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# FINAL REPORT

ON THE

# MID-PLAINS DIVISION OF THE ARTESIAN AND UNDERFLOW INVESTIGATION BETWEEN THE NINETY-SEVENTH MERIDIAN OF LONGITUDE WEST OF GREENWICH AND THE FOOTHILLS OF THE ROCKY MOUNTAINS,

BY

SPECIAL AGENT J. W. GREGORY,

OF GARDEN CITY, KANSAS;

AND

# A SPECIAL REPORT ON CERTAIN ARTESIAN CONDITIONS IN THE STATE OF SOUTH DAKOTA,

BY

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ENGINEER FOR SOUTH DAKOTA.

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Under the direction of

THE SECRETARY OF AGRICULTURE.

(OFFICE OF IRRIGATION INQUIRY.)

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## PART IV.

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# THE UNDERWATERS OF THE GREAT PLAINS.

## A REPORT

BY

## J. W. GREGORY,

SPECIAL AGENT OF ARTESIAN AND UNDERFLOW INVESTIGATION.

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# THE UNDERWATERS OF THE GREAT PLAINS.

The field of my investigation, under the United States Department of Agriculture, is situated in western Nebraska, Kansas, Oklahoma, and eastern Colorado, bounded, substantially, by the thirty-sixth and forty-third parallels of latitude and the ninety-seventh and one hundred and fourth meridians of longitude. This region has been officially designated the "middle division." It contains more than 200,000 square miles and above 130,000,000 acres of territory. That portion situated west of the one hundredth meridian embraces at least 75,000,000 acres.

The subject of investigation is the subterranean water resources of the division.

Any conclusions at the present stage of developmont, concerning the subterranean waters of this mid-plain country, which are or which may be available for use in irrigation, must be largely drawn from a multiplicity of facts and indications, many of which, examined and considered alone, would appear small, perhaps insignificant. But so clear are the evidences which may be found by the earnest inquirer of unprejudiced mind that, whereas the idea that there could be any appreciable supply of water obtained here in a practicable manner from subterranean sources for irrigation uses scarcely could command respectful attention a score of months ago, it has now become a matter of common belief and acceptance; and not only have considerable sums of money been already invested in irrigation works, which will depend upon subwaters to a large extent, but indications multiply that works of this kind will very greatly increase in number in the near future, and that the expenditure of capital in such works will reach large amounts, with very satisfactory indications of the judiciousness of such expenditure.

Before entering upon details as to the existence, quantity, and availability of these sub-water supplies, it may be well to take under consideration the characteristics of the country under examination as to surface, soil, climate, precipitation, etc., with a view to making clear whether there be any need of searching here for subterranean water supplies for any purpose other than ordinary domestic uses—in fact, for any purpose whatever. It is certainly judicious to inquire whether, on the one hand, the region in question so abounds in natural advantages as to stand in no need of artificially developed or applied water supply, or whether, on the other hand, it is for any reason unfit for habitation at all, or of such character as to become fit only for grazing purposes, since, in either case, the expenditure of time and money to secure water for irrigation would be useless expense.

## SURFACE CHARACTERISTICS.

First, then, the character of the surface in this division should be examined. The whole of the division consists, in general terms, of a broad, treeless plain. In detail, this is made up of alternating shallow valleys and low "divides," substantially parallel, extending from the mountains eastward and with a gradual downward slope in the same direction—being, in fact, a continuation of the mountain side and gradually approaching a level. On the one hundred and third meridian, the average declination of the surface eastward is about 15 feet per mile. The pitch or slope increases in degree westward, but toward the east decreases gradually until upon the one hundredth meridian the average inclination is about 7 feet per mile, and it still lessens further east.

As a rule, the divides are broad, and of comparatively smooth surface, the valleys narrow and comparatively shallow, and the rise from valley to upland is gradual. It is noticeable that the banks, benches, or uplands on the south side of any of these streams or valleys are invariably more precipitous, broken, and abrupt than on the north side. With rare exceptions, however, the waters of any stream in this portion of the plains can be led out, easily and cheaply, at almost any point along its course. The land at the highest portion of the intervening divides not infrequently rises 200, 300, and even 500 feet above the beds of the nearest streams or valleys. But this height is reached at such a distance from sources of water supply and at such gradations as render it easily possible to conduct water to any portion of the upland, except an occasional small knoll of a few acres in extent, rising with so great abruptness from the surrounding territory that the inclination of the general surface will not suffice to carry the water to its summit.

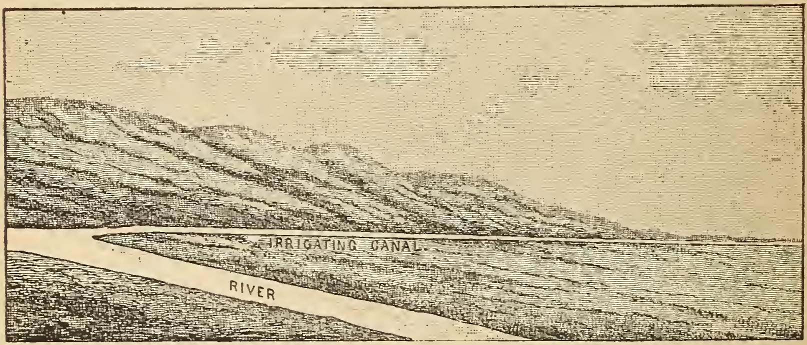

Fig. 1.—How water "runs up hill."

Many people find it difficult to understand how water can be run out from a river and up on to high land for use in irrigation. It is the rapid slope of the surface of the plains which makes this an easy matter. The general surface of the Arkansas Valley in Kansas, for example, has a fall of 7½ feet per mile, and gently sloping banks lead from the river up to the prairie, or "upland." If an irrigating canal be opened from the river, as shown in the accompanying cut, having a fall of 1½ feet per mile, it will climb 6 feet higher up the slope each mile of its progress, yet have fall enough for all practical purposes, and thus the water of a stream may be led from its bed to the highest upland.

There is an occasional strip or group of sand hills and, less frequently, a "patch" of rough country, broken by narrow cañons, but these two classes of unsightly and apparently undesirable land constitute but a small portion of the whole area, and are not, by any means, devoid of value.

How they may be utilized will be discussed in due order. Except a small spot, here and there, containing a few square feet or rods, at rare intervals, in river bottoms, there are no swamp lands in the division.

## SOIL.

The predominating soil of this division is a Tertiary marl, of great average depth and extraordinary fertility, of fine and even texture, and containing few or no bowlders. This marl is laid down in vast beds, forming almost unbroken areas of thousands of square miles in extent, and varying from three or four feet in depth to upward of a hundred feet in many places. A depth of forty to fifty feet is probably not above the average. This material forms an exceedingly rich and productive soil, and that which is newly thrown to the surface from the bottoms of cellars and wells proves as readily available for vegetable growth as that of the surface of the ground. Along the streams there may be found narrow bottoms of black loam, and, in other places, principally on second bottom lands, there are occasional outcrops of the "Tertiary grit" which underlies the marl, making a coarser and less strong, but a warmer and very productive soil. Now and then a very small area may be found where the underlying "mortar beds," elsewhere referred to, have been left without the prevailing covering of marl, and here there is but a thin, sedentary soil of little value, but such areas are so rare and so small in extent as to be practically inappreciable.

One feature of the economy of this region, which results from the characteristics of surface and soil, is the easy and cheap construction of remarkably excellent highways. By throwing up a slight grade across any portion of the marly plain, a roadway is formed which is hard, smooth, durable, costing next to nothing for maintenance, and over which, at all seasons and with an ordinary team, may be drawn with ease all the load the best farm wagon will bear. The sandy lands alone appreciably interrupt the continuity of such roadways over the whole of the division.

## CLIMATE.

There are, of course, very considerable variations in the temperature, etc., of different portions of so large an area, covering seven degrees of latitude and as many of longitude and ranging in elevation above sea level from 1,000 feet on the eastward limit to upward of 5,000 feet on the west; but the general characteristics of the division are a large percentage of bright, sunny days, the sun acting so powerfully in the growing season as to produce very rapid growth and ripening of vegetation; yet the heat of the sun in summer is so constantly tempered by cooling breezes that sunstroke is practically unknown and any sort of shade insures comfort. The clearness of the sky and the rarity of the atmosphere permit the rapid radiation of heat, so that summer nights are uniformly cool and pleasant, bringing rest and comfort to the inhabitants. Frosts are rare, disappearing early in the spring and not recurring until late in the autumn. As a rule very mild, pleasant autumn weather, undisturbed by storms, prevails until as late as January 1. After that time a brief season of somewhat severe storms may be expected, but they are of short duration. It is a winter of rare severity when farm-plowing can not be done in each month of it, at least as far west as the one hundred and second meridian. The sowing of fall wheat continues, as a rule, in southwest Kansas, northwest Oklahoma, and southeastern Colorado until late in December, and teams are busy breaking prairie; and by the middle of February, in almost any spring season, the work of the diligent farmer is well under headway and continues without appreciable interruption. The extraordinary dryness of the winter seasons in this region will be made apparent by a study of the tables given elsewhere, showing the average precipitation by months. This absence of moisture in the air renders the winters peculiarly favorable to stockgrowers, as live stock may be kept at a minimum expenditure for food and shelter and with small loss.

In brief, the climate is equable, sunny, healthful, and invigorating and winters are dry and mild.

## MOISTURE.

It would seem, then, that a region of country combining so many advantages of surface—so free from breaks and bogs, unvexed by stumps and stones, or other physical impediments, having a rich and inexhaustible soil, so many favorable elements of climate, such exceptional facilities for employing the ordinary methods of transportation—could not lack many of the essentials to the development of a rich and populous country. And, indeed, there is little lacking to make this region both densely populous and wonderfully rich and productive. The lack is suggested by the heading last above given. It is a lack of moisture. It must be plain that if, to the natural advantages already enumerated, there could be added a sufficiency of moisture to mature crops, there would then be nothing lacking to enable the dwellers in such a region to be eminently successful in all forms and departments of agriculture.

For decades this region was known as the "Great American Desert," had been pronounced, by well-informed persons, unfit for the habitation of civilized people ; yet it was afterwards thrown open to settlement as agricultural land and actually settled as such by home-seekers, upon the invitation of the General Government. There must have been, therefore, misjudgment on one side or the other. As a matter of fact, there was misjudgment on both sides. Both estimates were hasty and superficial. To understand wherein the mistakes lay and by what means the errors of the past may be made guide posts to success in the future, it is necessary to carefully examine and analyze ascertained facts regarding the water sources and resources of the mid-plain.

## RAINFALL.

The following tables show what has been the recorded rainfall from the 99th to the 104th meridian for a series of years. East of the 99th, while there is much adjacent territory in which irrigation will be so highly beneficial as to justify diligent effort and large expenditure on the part of the inhabitants to obtain it, it can scarcely be considered a necessity. West of the 104th meridian, the mountain snows and torrents will unquestionably furnish an abundant supply of water for all purposes.

The tables show the average monthly and annual precipitation by meridians, covering periods ranging in length from one to twenty-five years. In the table for any designated meridian are included the records of such places as lie within half a degree east or west of the meridian line. The extreme time from and to which such record ex-tends in each case is given, but the record is rarely continuous in the longer periods between the two dates given. The data for the tables were obtained from the official publications of the U. S. Signal-Service Office. Through some mischance, certain publications applied for failed to reach me and the tables are, consequently, lacking in desired fullness of detail, and the conclusions to be drawn from what they indicate are necessarily less weighty and satisfactory than it was hoped they might be. These records embrace the results of observations at twenty-five places scattered throughout a strip of country 1 degree of longitude in width, having the 99th meridian west from Greenwich as its meridian line and ranging from 44° 2′ north latitude down to 26° 23′; of twenty places similarly situated as to the 100th meridian and ranging from 42° 46′ north latitude down to 27° 32′; of six places having the 101st meridian as an axis and ranging in latitude from 42° 50′ to 29° 42′; of four places on the 102d meridian, the range of latitude being from 41° down to 30° 46′; of eight places on the 103d meridian, latitude 44° 04′ to 30° 20′; and of eight places ranging along the 104th meridian, from 42° 14′ to 30° 36.′ The results given are the averages per month and per annum of precipitation at the places and for the periods indicated.

*Geographical arrangement of places, giving their latitude, longitude, elevation, and length of record.*

99TH MERIDIAN.

| Name of place. | Latitude. | Longitude. | Elevation. | Record. | | | |
|---|---|---|---|---|---|---|---|
| | | | | Time. | | From— | To (inclusive). |
| | ° ′ | ° ′ | | Yrs. | m. | | |
| Fort Hale, S. Dak | 44 02 | 99 26 | 3, 245 | 5 | 5 | Jan., 1879 | May, 1884 |
| Fort Randall, S. Dak | 43 04 | 98 42 | 1, 245 | 32 | 0 | Nov., 1856 | Mar., 1890 |
| Richmond, Nebr | 42 36 | 99 09 | ........ | 1 | 6 | Apr., 1875 | Sept., 1876 |
| Sargent, Nebr | 41 38 | 99 22 | ........ | 3 | 10 | Feb., 1883 | Mar., 1890 |
| Ansley, Nebr | 41 15 | 99 22 | ........ | 1 | 5 | Nov., 1888 | Mar., 1890 |
| Fort Hartsuff, Nebr | 41 43 | 99 00 | ........ | 5 | 9 | Sept., 1875 | May, 1881 |
| North Loup, Nebr | 41 28 | 98 50 | ........ | 1 | 4 | Nov., 1888 | Mar., 1890 |
| Ravenna, Nebr | 41 02 | 98 54 | ........ | 3 | 3 | Aug., 1886 | Mar., 1890 |
| Beaver Creek, Nebr | 41 00 | 98 57 | ........ | 3 | 10 | Jan., 1882 | July, 1886 |
| Keene, Nebr | 40 25 | 99 04 | ........ | 1 | 9 | Feb., 1884 | Dec., 1885 |
| Fort Kearney, Nebr | 40 38 | 98 57 | 2, 360 | 17 | 2 | Mar., 1849 | Oct., 1882 |
| Minden, Nebr | 40 29 | 98 57 | ........ | 5 | 8 | June, 1882 | Mar., 1890 |
| Inavale, Nebr | 40 05 | 98 37 | ........ | 2 | 1 | Jan., 1882 | May, 1885 |
| Fort Belknap, Tex | 33 08 | 98 46 | 1, 600 | 5 | 10 | Oct., 1852 | Dec., 1858 |
| Graham, Tex | 33 05 | 98 33 | ........ | 2 | 3 | Jan., 1881 | Apr., 1883 |
| Fort Griffin, Tex | 32 53 | 99 21 | ........ | 12 | 4 | Aug., 1869 | Apr., 1882 |
| Camp Colorado, Tex | 31 55 | 99 17 | ........ | 3 | 11 | Jan., 1857 | Dec., 1860 |
| Coleman City, Tex | 31 45 | 99 15 | ........ | 5 | 10 | July, 1877 | Ang., 1883 |
| Mason, Tex | 30 45 | 99 05 | 1, 200 | 9 | 11 | Apr., 1852 | Mar., 1882 |
| Fort Mason, Tex | 30 48 | 99 15 | | | | | |
| Fredericksburg, Tex | 30 12 | 98 45 | ........ | 5 | 11 | Apr., 1877 | Feb., 1883 |
| Fort Martin Scott, Tex | 3 10 | 99 05 | 1, 300 | 2 | 3 | Jan., 1850 | Mar., 1852 |
| Camp Verde, Tex | 30 00 | 99 10 | 1, 400 | 5 | 9 | Jan., 1857 | Feb., 1869 |
| Castroville, Tex | 29 15 | 98 45 | ........ | 4 | 8 | Aug., 1877 | Mar., 1882 |
| Fort Ewell, Tex | 28 10 | 99 00 | 200 | 2 | 0 | Oct., 1852 | Sept., 1854 |
| Ringgold Barracks, Tex | 26 28 | 98 45 | 521 | 26 | 9 | Sept., 1849 | Dec., 1887 |
| Rio Grande City, Tex | 26 23 | 98 48 | 269 | | | | |

100TH MERIDIAN.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Fort Niobrara, Nebr | 42 46 | 100 25 | ........ | 7 | 3 | Aug., 1880 | Mar., 1890 |
| Fort McPherson, Nebr | 41 00 | 100 03 | 2, 695 | 2 | 9 | Nov., 1886 | Apr., 1880 |
| Red Willow, Nebr | 40 14 | 100 30 | ........ | 5 | 7 | Jan., 1882 | June, 1889 |
| Allison, Kans | 39 34 | 100 16 | ........ | 6 | 6 | Oct., 1883 | Mar., 1890 |
| Buffalo Park, Kans | 39 07 | 100 21 | 2, 755 | 3 | 4 | Jan., 1885 | Feb., 1890 |
| Dodge City, Kans | 37 54 | 100 02 | 2, 493 | 16 | 0 | Jan., 1875 | Dec., 1890 |
| Fort Elliott, Tex | 35 30 | 100 21 | ........ | 8 | 0 | Dec., 1879 | Dec., 1887 |

*Geographical arrangement of places, giving their latitude, longitude, etc.*—Continued.

### 100TH MERIDIAN—Continued.

| Name of place. | Latitude. | Longitude. | Elevation. | Record. | | |
|---|---|---|---|---|---|---|
| | | | | Time. | From— | To (inclusive). |
| | ° ′ | ° ′ | | *Yrs. m.* | | |
| Phantom Hill, Tex | 32 30 | 99 45 | 2,300 | 1 6 | Sept., 1852 | Feb., 1854 |
| Abilene, Tex | 32 26 | 99 37 | ........ | 2 3 | Oct., 1885 | Dec., 1887 |
| Fort Concho, Tex | 31 32 | 100 20 | 2,160 | 15 1 | Aug., 1872 | Nov., 1887 |
| Fort Chadbourne, Tex | 31 58 | 100 15 | 2,120 | 8 7 | May, 1852 | Dec., 1860 |
| Fort Terrett, Tex | 30 23 | 100 16 | 1,320 | 1 9 | Apr., 1852 | Dec., 1853 |
| Fort McKavett, Tex | 30 48 | 100 06 | 2,060 | 17 9 | Apr., 1852 | Feb., 1883 |
| Bracketville, Tex | 29 20 | 100 12 | ........ | 6 1 | May, 1877 | May, 1883 |
| Fort Clark, Tex | 29 17 | 100 25 | 1,000 | 16 5 | Aug., 1852 | Aug., 1886 |
| Uvalde, Tex | 29 15 | 99 45 | ........ | 6 1 | Apr., 1877 | May, 1883 |
| Eagle Pass, Tex | 28 43 | 100 30 | ........ | 5 11 | July, 1877 | May, 1883 |
| Fort Duncan, Tex | 28 39 | 100 30 | 1,460 | 16 4 | Oct., 1849 | Oct., 1879 |
| Fort Inge, Tex | 29 10 | 99 50 | 845 | 7 4 | Nov., 1849 | Dec., 1860 |
| Fort McIntosh, Tex | 27 35 | 99 48 | 806 | 22 7 | July, 1849 | Dec., 1887 |
| Laredo, Tex | 27 32 | 99 26 | 401 | | | |

### 101ST MERIDIAN.

| Name of place. | Latitude. | Longitude. | Elevation. | Time. | From— | To (inclusive). |
|---|---|---|---|---|---|---|
| Valentine, Nebr | 42 50 | 100 32 | 2,613 | 4 6 | Sept., 1885 | Mar., 1890 |
| North Platte, Nebr | 41 08 | 100 45 | 2,841 | 15 6 | Oct., 1875 | Mar., 1890 |
| Culbertson, Nebr | 40 12 | 100 48 | 2,572 | 2 6 | July, 1887 | Mar., 1890 |
| Monument, Kans | 39 06 | 101 01 | 3,180 | 4 10 | Jan., 1885 | Feb., 1890 |
| Silver Falls, Tex | 33 48 | 101 08 | ........ | 1 10 | Jan., 1886 | Nov., 1887 |
| Camp Hudson, Tex | 29 42 | 101 10 | ....... | 2 7 | May, 1858 | Dec., 1860 |

### 102D MERIDIAN.

| Name of place. | Latitude. | Longitude. | Elevation. | Time. | From— | To (inclusive). |
|---|---|---|---|---|---|---|
| Fort Sedgwick, Colo | 41 00 | 102 30 | 3,060 | 4 0 | Apr., 1867 | Apr., 1871 |
| Fort Wallace, Kans | 38 54 | 101 33 | 3,301 | 14 8 | Jan., 1870 | Mar., 1890 |
| Midland, Tex | 31 57 | 102 04 | ........ | 2 0 | Nov., 1885 | Nov., 1887 |
| Fort Lancaster, Tex | 30 46 | 101 48 | 2,350 | 4 6 | July, 1856 | Dec., 1860 |

### 103D MERIDIAN.

| Name of place. | Latitude. | Longitude. | Elevation. | Time. | From— | To (inclusive). |
|---|---|---|---|---|---|---|
| Rapid City, S. Dak | 44 04 | 103 17 | 3,280 | 4 7 | Feb., 1881 | Mar., 1890 |
| Fort Robinson, Nebr | 42 39 | 103 24 | ........ | 6 8 | July, 1883 | Mar., 1890 |
| Camp Sheridan, Nebr | 42 51 | 102 39 | ........ | 4 8 | July, 1876 | Mar., 1881 |
| Hay Springs, Nebr | 42 40 | 102 38 | ........ | 4 3 | Jan., 1886 | Mar., 1890 |
| Fort Sidney, Nebr | 41 09 | 102 59 | 4,090 | 12 0 | Jan., 1872 | Mar., 1890 |
| Las Animas, Colo | 38 05 | 103 07 | 3,899 | 19 1 | Jan., 1869 | Dec., 1887 |
| Fort Lyon, Colo | 30 06 | 103 08 | 4,000 | | | |
| Fort Bascom, N. Mex | 35 23 | 103 27 | 4,000 | 2 3 | Dec., 1864 | Oct., 1870 |
| Fort Stockton, Tex | 30 20 | 102 52 | 4,930 | 17 0 | Oct., 1859 | June, 1886 |

### 104TH MERIDIAN.

| Name of place. | Latitude. | Longitude. | Elevation. | Time. | From— | To (inclusive). |
|---|---|---|---|---|---|---|
| Fort Laramie, Wyo | 42 14 | 104 29 | 4,519 | 22 10 | Sept., 1849 | Dec., 1887 |
| Hat Creek, Wyo | 42 05 | 104 20 | ........ | 2 6 | Oct., 1877 | Sept., 1880 |
| Cheyenne, Wyo | 41 08 | 104 18 | 6,105 | 19 11 | Jan., 1870 | Mar., 1890 |
| Kimball, Nebr | 41 13 | 103 40 | ........ | 2 1 | Oct., 1887 | Mar., 1890 |
| Fort Reynolds, Colo | 38 15 | 104 12 | 4,300 | 3 0 | Jan., 1869 | Mar., 1872 |
| Trinidad, Colo | 37 07 | 104 30 | 6,070 | 3 6 | Aug., 1877 | Feb., 1881 |
| Fort Sumner, N. Mex | 34 19 | 104 09 | ....... | 4 8 | May, 1864 | July, 1889 |
| Fort Davis, Tex | 30 36 | 103 36 | 4,700 | 19 3 | Jan., 1855 | Dec., 1887 |

*Rainfall in inches, showing the average values for each month.*

### 99TH MERIDIAN.

| Name of place. | Jan. | Feb. | Mch | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fort Hale, S. Dak | 0. 56 | 1. 09 | 0. 97 | 1. 43 | 3. 00 | 3. 69 | 2. 39 | 2. 52 | 0. 70 | 2. 32 | 0. 25 | 0. 49 | 19. 79 |
| Fort Randall, S. Dak | 0. 41 | 0. 59 | 1. 04 | 1. 75 | 3. 54 | 3. 28 | 2. 71 | 2. 60 | 2. 02 | 1. 31 | 0. 49 | 0. 84 | 20. 50 |
| Richmond, Nebr | 0. 36 | 1. 62 | 1. 33 | 2. 16 | 3. 66 | 2. 30 | 5. 04 | 7. 59 | 1. 81 | 0. 94 | 0. 75 | 0. 19 | 27. 85 |
| Sargent, Nebr | 0. 53 | 0. 29 | 0. 81 | 2. 41 | 4. 04 | 3. 25 | 4. 12 | 3. 11 | 1. 29 | 0. 48 | 0. 58 | 1. 35 | 22. 26 |
| Ansley, Nebr | 0. 35 | 0. 10 | 1. 70 | 0. 50 | 1. 30 | 2. 93 | 8. 90 | 1. 23 | 0. 40 | 0. 60 | 0. 40 | 0. 30 | 18. 71 |
| Fort Hartsuff, Nebr | 0. 21 | 0. 29 | 0. 60 | 1. 32 | 3. 93 | 4. 16 | 4. 34 | 1. 45 | 2. 32 | 1. 38 | 0. 28 | 0. 57 | 20. 83 |
| North Loup, Nebr | 1. 09 | 0. 08 | 0. 68 | 1. 88 | 0. 98 | 3. 84 | 10. 37 | 1. 58 | 1. 60 | 0. 45 | 0. 54 | 0. 35 | 23. 44 |
| Ravenna, Nebr | 0. 78 | 0. 66 | 1. 46 | 3. 19 | 2. 90 | 3. 95 | 6. 07 | 3. 33 | 1. 84 | 0. 62 | 0. 78 | 0. 62 | 26. 20 |
| Beaver Creek, Nebr | 0. 42 | 0. 70 | 1. 03 | 2. 92 | 4. 31 | 2. 63 | 4. 09 | 3. 35 | 1. 58 | 2. 20 | 0. 43 | 0. 76 | 24. 42 |
| Keene, Nebr | 0. 35 | 0. 46 | 0. 64 | 3. 44 | 3. 22 | 1. 36 | 6. 18 | 2. 80 | 1. 20 | 2. 20 | 0. 62 | 1. 05 | 23. 52 |
| Fort Kearney, Nebr | 0. 59 | 0. 43 | 1. 17 | 2. 31 | 4. 48 | 3. 60 | 4. 66 | 2. 46 | 2. 27 | 1. 65 | 0. 97 | 0. 55 | 25. 44 |
| Minden, Nebr | 0. 87 | 0. 85 | 1. 49 | 4. 54 | 5. 19 | 4. 07 | 6. 09 | 3. 91 | 1. 80 | 2. 48 | 1. 04 | 0. 92 | 33. 25 |
| Inavale, Nebr | 0. 20 | 0. 53 | 0. 85 | 4. 79 | 5. 28 | 5. 13 | 2. 45 | 2. 50 | 1. 25 | 2. 20 | 0. 60 | 0. 20 | 25. 98 |
| Fort Belknap, Tex | 0. 47 | 2. 29 | 1. 32 | 0. 88 | 4. 21 | 3. 98 | 2. 49 | 2. 97 | 2. 77 | 2. 92 | 2. 65 | 1. 10 | 28. 05 |
| Graham, Tex | 1. 30 | 2. 09 | 1. 48 | 1. 73 | 2. 86 | 2. 03 | 5. 24 | 5. 16 | 6. 58 | 1. 98 | 1. 89 | 1. 36 | 35. 70 |
| Fort Griffin, Tex | 1. 05 | 1. 14 | 0. 75 | 1. 69 | 3. 00 | 3. 78 | 2. 69 | 1. 14 | 2. 73 | 1. 95 | 1. 60 | 2. 11 | 23. 63 |
| Camp Colorado, Tex | 0. 92 | 0. 75 | 0. 63 | 2. 42 | 1. 14 | 1. 22 | 1. 03 | 5. 44 | 4. 27 | 1. 74 | 2. 46 | 2. 08 | 24. 10 |
| Coleman City, Tex | 1. 04 | 1. 52 | 1. 72 | 1. 67 | 3. 67 | 3. 11 | 3. 99 | 2. 28 | 4. 51 | 2. 28 | 1. 58 | 2. 33 | 29. 70 |
| Mason, Tex<br>Fort Mason, Tex | 1. 17 | 1. 64 | 1. 16 | 2. 25 | 3. 01 | 2. 00 | 3. 17 | 2. 85 | 3. 92 | 2. 22 | 1. 33 | 1. 80 | 26. 52 |
| Fredericksburg, Tex | 1. 02 | 1. 65 | 1. 46 | 3. 14 | 4. 22 | 1. 96 | 2. 95 | 2. 28 | 3. 73 | 2. 38 | 2. 19 | 1. 40 | 28. 38 |
| Fort Martin Scott, Tex | 0. 80 | 2. 98 | 5. 82 | 6. 48 | 2. 31 | 5. 18 | 1. 25 | 1. 28 | 1. 31 | 1. 07 | 2. 68 | 1. 87 | 33. 03 |
| Camp Verde, Tex | 1. 19 | 1. 41 | 2. 47 | 1. 34 | 2. 30 | 2. 37 | 2. 31 | 5. 13 | 4. 47 | 1. 89 | 1. 94 | 2. 45 | 29. 27 |
| Castroville, Tex | 1. 36 | 1. 44 | 1. 33 | 2. 31 | 3. 08 | 1. 31 | 3. 10 | 2. 70 | 1. 92 | 1. 71 | 1. 22 | 1. 37 | 22. 85 |
| Fort Ewell, Tex | 0. 76 | 4. 73 | 0. 71 | 1. 12 | 5. 11 | 2. 85 | 2. 90 | 2. 43 | 4. 91 | 2. 36 | 0. 49 | 1. 16 | 34. 53 |
| Ringgold Barracks, Tex<br>Rio Grande City, Tex | 1. 06 | 0. 98 | 1. 04 | 1. 05 | 2. 78 | 2. 79 | 1. 51 | 2. 94 | 3. 70 | 1. 97 | 0. 98 | 1. 21 | 22. 01 |
| Averages | 0. 76 | 1. 21 | 1. 35 | 2. 35 | 3. 34 | 3. 20 | 4. 00 | 3. 00 | 2. 68 | 1. 73 | 1. 15 | 1. 14 | 25. 48 |

### 100TH MERIDIAN.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fort Niobrara, Nebr | 0. 47 | 0. 54 | 0. 97 | 2. 65 | 3. 94 | 2. 85 | 2. 31 | 1. 41 | 1. 29 | 1. 23 | 0. 33 | 0. 77 | 18. 76 |
| Fort McPherson, Nebr | 0. 28 | 0. 42 | 0. 61 | 1. 54 | 3. 73 | 3. 34 | 2. 58 | 1. 87 | 1. 83 | 0. 48 | 0. 37 | 0. 61 | 17. 66 |
| Red Willow, Nebr | 0. 82 | 0. 91 | 0. 93 | 2. 49 | 3. 36 | 3. 39 | 2. 88 | 3. 18 | 1. 37 | 1. 24 | 0. 33 | 0. 84 | 21. 74 |
| Allison, Kans | 1. 23 | 0. 71 | 1. 15 | 2. 91 | 4. 00 | 2. 94 | 4. 54 | 2. 49 | 1. 75 | 1. 29 | 0. 37 | 0. 76 | 24. 14 |
| Buffalo Park, Kans | 0. 92 | 0. 56 | 0. 20 | 1. 85 | 1. 36 | 2. 13 | 4. 10 | 3. 93 | 1. 30 | 1. 36 | 0. 44 | 0. 50 | 18. 35 |
| Fort Elliott, Tex | 0. 31 | 0. 52 | 0. 61 | 2. 14 | 5. 32 | 3. 79 | 2. 66 | 3. 62 | 2. 00 | 2. 82 | 0. 54 | 0. 81 | 25. 14 |
| Phanton Hill, Tex | 0. 26 | 0. 80 | 0. 54 | 0. 45 | 2. 85 | 2. 90 | 1. 15 | 0. 03 | 3. 55 | 3. 41 | 1. 34 | 0. 94 | 18. 22 |
| Abilene, Tex | 0. 09 | 0. 91 | 1. 25 | 2. 06 | 2. 14 | 3. 34 | 2. 10 | 1. 56 | 3. 40 | 3. 21 | 0. 58 | 0. 85 | 21. 49 |
| Fort Concho, Tex | 0. 80 | 0. 76 | 0. 98 | 1. 27 | 2. 83 | 2. 20 | 2. 26 | 2. 50 | 3. 00 | 1. 49 | 0. 78 | 0. 15 | 19. 02 |
| Fort Chadbourne, Tex | 0. 94 | 1. 37 | 0. 85 | 1. 53 | 3. 39 | 2. 55 | 1. 71 | 2. 27 | 3. 30 | 2. 03 | 1. 70 | 1. 21 | 22. 85 |
| Fort Terret, Tex | 0. 80 | 1. 54 | 1. 15 | 0. 97 | 3. 98 | 5. 14 | 3. 36 | 1. 72 | 2. 91 | 4. 21 | 0. 64 | 0. 76 | 27. 18 |
| Fort McKavett, Tex | 0. 92 | 1. 57 | 1. 20 | 0. 95 | 2. 64 | 2. 06 | 2. 87 | 2. 50 | 3. 79 | 2. 24 | 1. 53 | 1. 64 | 22. 97 |
| Bracketville, Tex | 1. 22 | 0. 70 | 2. 00 | 2. 38 | 4. 94 | 2. 16 | 2. 20 | 2. 61 | 2. 70 | 3. 30 | 1. 09 | 1. 08 | 26. 38 |
| Fort Clark, Tex | 0. 57 | 1. 26 | 0. 94 | 1. 04 | 2. 14 | 3. 42 | 1. 22 | 2. 23 | 3. 93 | 1. 41 | 1. 45 | 2. 45 | 22. 06 |
| Fort Lincoln, Tex | 0. 13 | 4. 00 | 3. 50 | 1. 86 | 2. 89 | 2. 07 | 1. 00 | 0. 39 | 1. 54 | 1. 36 | 2. 01 | 0. 98 | 21. 73 |
| Uvalde, Tex | 0. 84 | 1. 12 | 2. 07 | 1. 82 | 2. 84 | 0. 90 | 2. 34 | 3. 19 | 2. 74 | 1. 21 | 1. 45 | 1. 64 | 22. 06 |
| Eagle Pass, Tex | 1. 12 | 0. 97 | 1. 80 | 1. 19 | 3. 61 | 2. 11 | 3. 34 | 3. 54 | 3. 54 | 1. 92 | 0. 60 | 1. 19 | 24. 93 |
| Fort Duncan, Tex | 0. 33 | 0. 49 | 1. 28 | 0. 86 | 1. 73 | 3. 80 | 2. 11 | 1. 91 | 3. 52 | 1. 15 | 1. 17 | 1. 39 | 20. 74 |
| Fort Inge, Tex | 0. 70 | 1. 96 | 1. 50 | 1. 52 | 2. 36 | 4. 51 | 2. 66 | 2. 50 | 2. 30 | 2. 77 | 1. 67 | 0. 78 | 25. 32 |
| Fort McIntosh, Tex<br>Laredo, Tex | 0. 67 | 1. 37 | 0. 92 | 0. 87 | 2. 24 | 3. 01 | 1. 90 | 2. 80 | 2. 56 | 1. 49 | 0. 84 | 1. 18 | 19. 85 |
| Averages | 0. 69 | 0. 95 | 1. 09 | 1. 61 | 3. 15 | 2. 99 | 2. 57 | 2. 45 | 2. 56 | 1. 97 | 0. 89 | 0. 96 | 21. 45 |

### 101ST MERIDIAN.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Valentine, Nebr | 0. 50 | 0. 63 | 1. 11 | 2. 21 | 4. 32 | 2. 86 | 3. 00 | 1. 73 | 1. 43 | 0. 92 | 0. 35 | 0. 38 | 19. 44 |
| North Platte, Nebr | 0. 48 | 0. 35 | 0. 62 | 2. 03 | 3. 09 | 3. 34 | 3. 00 | 2. 47 | 1. 62 | 1. 12 | 0. 38 | 0. 68 | 19. 18 |
| Culbertson, Nebr | 0. 38 | 0. 26 | 0. 70 | 2. 66 | 3. 53 | 2. 67 | 4. 35 | 3. 25 | 1. 74 | 0. 76 | 0. 34 | 0. 85 | 20. 33 |
| Monument, Kans | 0. 28 | 0. 60 | 0. 54 | 3. 33 | 2. 08 | 3. 33 | 2. 63 | 2. 39 | 0. 95 | 1. 20 | 0. 49 | 0. 10 | 18. 82 |
| Silver Falls, Tex | (T) | 1. 07 | ..... | 1. 90 | 2. 13 | 1. 02 | 2. 48 | 2. 90 | 3. 38 | 2. 77 | 0. 17 | (T) | 17. 22 |
| Camp Hudson, Tex | 0. 76 | 0. 13 | 0. 11 | 1. 42 | 1. 60 | 2. 13 | 0. 08 | 3. 33 | 0. 99 | 0. 97 | 0. 19 | 0. 42 | 12. 13 |
| Averages | 0. 40 | 0. 50 | 0. 51 | 2. 26 | 2. 79 | 2. 48 | 2. 46 | 2. 74 | 1. 69 | 1. 29 | 0. 27 | 0. 29 | 17. 85 |

### 102D MERIDIAN.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fort Sedgwick, Colo | 0. 79 | 1. 77 | 0. 95 | 2. 22 | 2. 13 | 0. 26 | 1. 21 | 2. 00 | 3. 00 | 0. 40 | 0. 03 | 0. 67 | 15. 43 |
| Fort Wallace, Kans | 0. 28 | 0. 34 | 0. 37 | 1. 36 | 3. 09 | 2. 43 | 3. 47 | 1. 82 | 1. 64 | 1. 01 | 0. 44 | 0. 40 | 16. 65 |
| Midland, Tex | 0. 01 | 0. 16 | 0. 22 | 0. 70 | 3. 41 | 1. 46 | 0. 75 | 1. 62 | 0. 86 | 1. 46 | 0. 13 | 0. 08 | 10. 86 |
| Fort Lancaster, Tex | 1. 30 | 0. 41 | 0. 35 | 2. 51 | 1. 98 | 3. 59 | 1. 96 | 3. 46 | 4. 88 | 2. 91 | 0. 93 | 1. 97 | 26. 25 |
| Averages | 0. 60 | 0. 67 | 0. 47 | 1. 70 | 2. 65 | 1. 94 | 1. 85 | 2. 23 | 2. 60 | 1. 45 | 0. 38 | 0. 78 | 17. 30 |

*Rainfall in inches, showing the average values for each month*—Continued.

103D MERIDIAN.

| Name of place. | Jan. | Feb. | Mch. | Apr. | May. | June. | July. | Aug. | Sept. | Oct | Nov. | Dec. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rapid City, S. Dak | 0.34 | 0.84 | 0.82 | 1.99 | 5.19 | 4.11 | 2.66 | 1.43 | 0.58 | 0.54 | 0.38 | 0.31 | 19.19 |
| Fort Robinson, Nebr | 0.44 | 0.64 | 1.17 | 1.63 | 3.15 | 2.03 | 1.94 | 1.96 | 0.46 | 1.86 | 0.63 | 0.84 | 16.75 |
| Camp Sheridan, Nebr | 0.32 | 0.51 | 1.41 | 1.64 | 3.36 | 3.50 | 2.97 | 1.52 | 0.90 | 1.07 | 0.73 | 0.50 | 18.43 |
| Hay Springs, Nebr | 0.57 | 0.78 | 1.10 | 1.82 | 4.64 | 3.23 | 2.38 | 3.10 | 0.45 | 0.64 | 0.76 | 0.80 | 20.27 |
| Fort Sidney, Nebr | 0.44 | 0.50 | 0.86 | 1.45 | 2.83 | 1.21 | 2.50 | 1.91 | 1.11 | 0.79 | 0.33 | 0.30 | 14.23 |
| Las Animas, Colo<br>Fort Lyon, Colo | 0.14 | 0.23 | 0.45 | 1.23 | 2.11 | 1.58 | 2.22 | 2.07 | 1.04 | 0.61 | 0.25 | 0.33 | 12.26 |
| Fort Bascom, N. Mex | 0.13 | ..... | 0.09 | 1.55 | 1.46 | 2.24 | 2.99 | 1.86 | 0.27 | 1.89 | 0.75 | 0.50 | 13.73 |
| Fort Stockton, Tex | 0.29 | 0.52 | 0.86 | 0.41 | 1.58 | 2.23 | 1.87 | 2.62 | 3.88 | 1.25 | 0.74 | 0.85 | 17.10 |
| Averages | 0.33 | 0.50 | 0.86 | 1.46 | 3.04 | 2.52 | 2.44 | 2.06 | 1.09 | 1.08 | 0.57 | 0.55 | 16.49 |

104TH MERIDIAN.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fort Laramie, Wyo | 0.52 | 0.53 | 0.56 | 1.27 | 2.64 | 1.39 | 1.52 | 1.13 | 0.88 | 0.85 | 0.51 | 0.50 | 12.30 |
| Hat Creek, Wyo | 0.02 | 0.04 | 0.07 | 3.48 | 2.92 | 1.00 | 1.20 | 1.70 | 1.12 | 2.00 | 1.46 | 0.25 | 17.26 |
| Cheyenne, Wyo | 0.28 | 0.29 | 0.63 | 1.38 | 2.00 | 1.46 | 1.64 | 1.46 | 0.98 | 0.67 | 0.31 | 0.22 | 11.32 |
| Kimball, Nebr | 0.25 | 0.30 | 0.25 | 0.47 | 3.72 | 1.85 | 2.20 | 1.68 | 0.01 | 0.38 | 0.10 | 0 25 | 11.46 |
| Fort Reynolds, Colo | 0.70 | 0.89 | 0.72 | 1.09 | 1.69 | 0.80 | 1.51 | 1.31 | 1.90 | 0.49 | 2.57 | 0.36 | 14.03 |
| Trinidad, Colo | 0.17 | 1.15 | 0.04 | 1.03 | 2.43 | 5.40 | 3.24 | 3.26 | 1.27 | 1.41 | 1.65 | 0.68 | 21.73 |
| Fort Sumner, N. Mex | 0.23 | 0.35 | 0.97 | 0.36 | 1.05 | 1.95 | 3.18 | 2.37 | 1.47 | 1.21 | 0.64 | 1.24 | 15.02 |
| Fort Davis, Tex | 0.50 | 0.43 | 0.42 | 0.60 | 1.07 | 1.98 | 3.43 | 3.97 | 2.97 | 1.46 | 0.44 | 0.44 | 17.71 |
| Averages | 0.33 | 0.47 | 0.46 | 1.21 | 2.19 | 1.98 | 2.24 | 2.11 | 1.33 | 1.06 | 0.96 | 0.49 | 14.85 |

It is to be regretted that the records of a larger number of stations could not have been obtained, at least for the one hundred and second, one hundred and third, and one hundred and fourth meridians, as a full and accurate knowledge of the amount of precipitation upon those meridians is of more than ordinary importance. Taking such data as could be obtained, however, some interesting facts are presented. One of the most important is the large proportion of the annual rainfall precipitated in the half of the year in which moisture is of great utility. The following table gives, in inches and hundredths, the mean annual precipitation, by meridians, as shown by the foregoing tables, and the quantity precipitated in the six months from April to September, inclusive. The next column shows the percentage which this quantity is of the annual rainfall, and the last exhibits, in inches and hundredths, what would be the annual precipitation were the average of the six "growing" months maintained throughout the year:

SUMMARY.

| Meridian. | Mean annual precipitation. | Rainfall from April to September inclusive. | Percentage of "summer rain." | Annual precipitation on "summer rain" basis. |
|---|---|---|---|---|
| 99th | 25.48 | 18.57 | 73— | 37.14 |
| 100th | 21.45 | 15.33 | 72— | 30.66 |
| 101st | 17.85 | 14.42 | 81— | 28.84 |
| 102d | 17.30 | 12.97 | 75— | 25.94 |
| 103d | 16.40 | 12.61 | 76+ | 25.22 |
| 104th | 14.85 | 11.06 | 73+ | 22.12 |
| Averages | 18.89 | 14.16 | 75— | 28.32 |

An inspection of this table shows that the variation in amount of rainfall from the one hundred and first meridian to the one hundred and third is comparatively slight, that the average for the entire division is 18.89 inches per annum, and that of this amount three-fourths fall between the 1st of April and the last of September. Were a proportionate precipitation enjoyed throughout the year, the annual measure would be 28.32 inches. As experience has shown that the late fall, winter, and early spring rains are sufficient, except in rare instances, to sprout and maintain fall grains, and to put forward the early spring growth of vegetation, the region practically enjoys an annual precipitation of the value of 28 inches, and were it not for modifying facts this would be ample to make the plains country a delightful and prosperous farming country, because the comparative absence of storms and moisture throughout the winter months adds greatly to the comfort both of man and beast, renders winter pasturage for stock both available and nutritious, and reduces necessary expenditures for shelter and feed to a minimum, beside being highly favorable to travel and the transportation of the products of the farm over the public highways.

Upon the question as to what annual quantity of moisture is necessary to the production of crops, I take the liberty of quoting the following extract from an official report of Gen. A. W. Greely, Chief Signal Officer, made in 1889. He says (Report on Rainfall in Washington, Oregon, etc., p. 8):

> As has been pointed out by the Director of the Geological Survey, the arid region of the United States includes more than four-tenths of the entire country, excluding Alaska. It is believed that the accomplished Director unintentionally overstated the case when he advanced the idea that those regions should be classed as arid or incapable of successful agriculture without irrigation where the rainfall is less than 20 inches annually. The statements put forth by him that, with 20 inches, agriculture will suffer drought, and will be fruitless many seasons in a long series, is equally true of regions over which as much as 25 or 30 inches fall annually. Indeed, during this very year, sections of the country where the annual rainfall ranged from 30 to 50 inches have been visited by most serious and protracted drought, which proved most disastrous to agricultural and other kindred interests.
>
> The point at which a region may be classed as arid and unfit for successful agriculture without irrigation should be lowered, it is believed, to 15 inches. The chief signal officer does not assert that this amount of annual rainfall will be sufficient for all crops, nor in all kinds of soil, nor at every elevation. Latitude, elevation, equable distribution of rainfall, humidity, and soil, all these are conditions which must be important factors in the problem. Exact observations upon these points are lacking in the United States, but in Australia observations and experiments have been made, covering now quite a number of years, on wheat (and this may be called a test crop).
>
> The fact that wheat can be grown without irrigation in a country where the annual rainfall is less than 20 inches is evidenced by official statistics from Dakota, which show that wheat is grown by tens of millions of bushels yearly in sections where the rainfall ranges from 20 inches downward. Indeed, the arid-region limit, based on 15 inches mean annual rainfall, is a most reliable one in that region, as is evinced by the fact that over 3,000,000 bushels of wheat are now grown annually in countries where the rainfall ranges from 15.1 down to 13.8. (See "Resources of Dakota, 1887," an official publication.)

So far as rainfall alone is concerned, it would appear, according to the foregoing estimates, that this region has enough and to spare under average conditions. This I believe is true. In fact, it unquestionably is true, and the authority just quoted contains other observations upon the same subject, which are both pertinent to this branch of my subject and exceedingly interesting. I quote from the report above cited:

> It is tolerably safe to assume that the data from isolated stations of quite high elevation, which tend to show large rainfall, do not entirely counterbalance the large number of small rainfalls over the country of least elevation, and that the average rainfall through the arid region, as shown by these maps, is really less than the average amount which actually falls over the entire region. (Page 10 of report.)

The great extent to which misapprehension as to the rainfall conditions of the arid regions has been corrected by these charts is evidenced by the fact that the area on which the mean annual rainfall is less than 10 inches, shown on statistical maps of the Tenth Census at 241,000 square miles, has been reduced to 126,000 square miles; while a similar reduction is shown in the area of country where the yearly rainfall is between 10 and 15 inches, which, given in the census chart at 385,000 square miles, is now limited to 259,000 square miles. In other words, the area over which less than 15 inches of rain falls annually has been reduced almost a quarter of a million (241,000) square miles. A large area of country charted on the statistical maps as having an average rainfall of less than 5 inches now entirely disappears in Texas, New Mexico, Utah, and Oregon, and is very materially reduced in Nevada, Arizona, and California. (Page 7 of report.)

The Chief Signal Officer puts it forward as his opinion that when Idaho, Nevada, Utah, New Mexico, and Arizona shall have been covered with rain gauges as completely as New York or New England, the final outcome of observation will indicate that the actual average of rainfall for this arid region is now understated by the census charts (Census of 1880) from 20 to 40, and by these from 10 to 15 per cent. (Page 11 of report.)

The Chief Signal Officer does not hesitate to express the opinion that the trans-Mississippi and trans-Missouri rainfall is slightly increasing, as a whole, though in certain localities it may be slightly decreasing from causes set forth above, and it seems most proper for him to put forth his strong conviction, even though it be not a certainty, when, as in this case, it will tend to reassure the agricultural population in the lately drouth-stricken districts of the West. There appears no possible reason to believe that the scanty rainfall of the past year or two will not be followed by increasing precipitation in the next few years, which will maintain the annual rainfall of these sections at the average, or even increase it. (Page 15 of report.)

If Gen. Greely's opinions, as expressed in the foregoing extracts, are correct—and plainsmen of experience will uniformly coincide with the views enunciated—we probably have a somewhat larger annual precipitation upon the Plains than the records show, and this will probably increase, at least to a slight extent, in the future.

But there are difficulties to be overcome which do not show forth upon rain charts nor tables of rainfall records. Although the distribution of the precipitation may be shown in detail, there is nothing in such charts and tables to indicate the destructive power of desiccating warm winds nor to record the damage they do. The occasional year of excessive drought shows clearly enough; but what it is which does the damage, even in years which, by chart and table, would appear the most favorable, is learned only by experience. That which works the most frequent and most widespread injury is a short period of hot, dry weather, characterized by brassy skies and warm, dry winds. This rarely lasts more nor less than two weeks, and almost invariably occupies the first two weeks in July. This brief drought period, occurring at such a time, injures everything except the very early and very late crops. It tends to prevent the proper filling of small grain, and by drying up the tassels of corn which has reached the tasseling stage precludes the harvesting of anything more from such a field than a crop of "fodder." Garden crops, too, and all others which would naturally be in their prime in midsummer are greatly injured and sometimes completely destroyed. After this midsummer simoon, as well as before, there are, as a rule, plentiful rains, and crops which can be matured before this annual visitation, or which can be grown afterward, give the farmer at least a partial return for his labor. So it is that some crops nearly always escape the drought, and the settler is thus tempted to try again and again in the hope that he will learn how to cope successfully with the peculiarities of the country, and some have succeeded after a fashion, but many others give up the fight after repeated failures. When water can be had, however, for irrigation, all forms and periods of drought and the hottest winds are successfully defied. A field of Indian corn, copiously irrigated, will flourish without the sign of a curling blade when winds are blowing so hot as to redden the eyelids of the passer by.

With sufficient facilities for irrigation to successfully resist this short period of midsummer drought, the farmer on the Plains could manage to do fairly well most years. With plentiful irrigation, he enjoys advantages far superior in many respects to the most favorably situated farmer who depends upon natural rainfall alone.

## STREAMS.

Few streams traverse this division, compared with any equal area in the humid region. The Niobrara, the North and South Plattes, the Republican, the Solomon, the Smoky Hill, the Arkansas, the Cimarron, and the Canadian comprise all of the more important streams of this large area. Frenchman Creek, the various Beavers, the three Sappas, the Prairie Dog, the Landsman, Ladder Creek, and innumerable Sand Creeks are among the more notable tributaries.

What are denominated "creeks" and "rivers" by the inhabitants of the Plains may be divided into three classes: First. Rivers of the mountains, which rise in some part of the great Rockies and flow with more or less steadiness, but having by far their greatest volume of water when the mountain snows melt in summer, running low at other times, gradually decreasing through fall, winter, and spring and often going quite dry at places along their middle courses, while at head and mouth they are perennial streams, though of greatly variable volume. The Arkansas, the Canadian, and the Plattes are the most important of these, and carry more water than any and all others. Second. Rivers of the plains, which have their sources in the plain itself, at a greater or less distance from the mountains, originating in systems of springs and being fed principally by the same. These supply less water than the more pretentious rivers which rise in the mountains, but their flow is much more steady and uniform. Droughts affect these but slightly, and though local rains swell their volume to a considerable degree at intervals such augmentation is largely local and of brief duration. Third. There are a great number of what may be called "dry creeks." These are more or less pretentious water courses in appearance, some of them of very considerable length and many possessing sandy beds and deep and wide channels, but no water visibly flows in them except immediately after a heavy local rain, and rarely is there running water throughout their whole length at any time, and their highest water flows only a few hours, soon disappearing into the sands or through fissures in their beds, or is discharged into larger streams to which these potential streams are tributary. That is, they are potential in the sense that they might, could, would, or should carry water. The traveler hailing from a humid region, where a "river" or a "creek" is taken for granted as containing water, soon finds that upon the Plains these terms are very commonly applied to what simply constitutes a very complete and well-appointed place for a stream.

One thing, to which allusion is made elsewhere, characterizes nearly all of the perennial streams found upon the Great Plains, viz, the traveler along the middle course of such a stream will often find, to his surprise, only a bed of apparently dry sand, though but a short distance below he saw a very considerable stream of water. Continuing on up the channel, he will find again and again limpid stretches of running water succeeded by reaches of dry, red gravel or fine, white sand. In the largest streams, this characteristic will be observed at the lowest stages of water at points along the middle course of the stream. Perennial water will be found toward the head and in a more or less extensive stretch of channel toward the mouth. In the smaller tributary streams, the perennial water will be found at the head, whether the stream rise in mountain or plain, and the dry sand bed will be found, if at all, at the mouth and extending thence upstream perhaps half or more than half the total length of the tributary. This characteristic is the result of the action of flood waters, originating in the upper courses of the streams, by which large quantities of sand and gravel are carried as far downstream as the rapid declivity of surface and narrowness of channel will suffice to hold such matter in suspension, or move it along by force of current. In the case of smaller streams, the tendency is to deposit detritus first at the point of discharge into a larger water course, the bank or drift thus formed tending gradually to extend itself upstream toward the torrential sources. In the large and long streams, this deposit will be made when the middle courses, of wider channel and more moderate fall, are reached, promoted no doubt by the obstructive deposits thrown into the channel from such tributaries as have just been described. The accompanying figure (Fig. 2) will illustrate how such deposits are formed, and why a stream will appear in places and be hidden from sight at others.

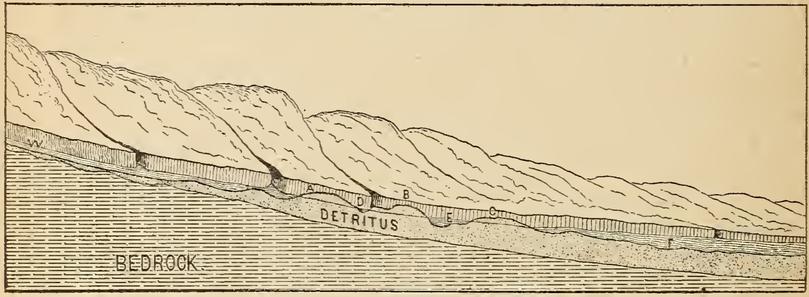

Fig. 2.—The disappearance of water in streams.

Here is roughly represented a longitudinal section of a stream on the plains, showing the underlying bedrock, the superincumbent sand in the channel, and the water line, W. Sand and gravel brought down from the upper portions of the stream, where the fall is great and the current swift, will be deposited in times of high water in sand waves, as at A, B, and C. One of these will often occupy a channel for miles. At low stages the water simply disappears below the surface of one of these deposits, but shows at low places as at *d* and *e*, and in the lower courses, as at F, there will be a perennial stream. This is dwelt upon at some length, because it has an important bearing upon what follows regarding the subwaters of this division.

All rivers of the plains present the same primary characteristics. Beginning at the head, many shallow ravines, locally denominated "draws," will be found beginning in a barely perceptible depression and gradually deepening as they draw near to a focal point or locality.

Two, three, a half dozen of these unite and a marked depression, too broad and shallow to be called a channel, leads on down the slope of the surface to meet others of the same kind as branches meet in the top of a tree. These draws are grass grown and their soil is not different from that of the surrounding prairie, except where more or less extensive outcrops of grit are found, and in the deeper portions where an accumulation of vegetable mold in small areas is succeeded at lower levels by a narrow, sandy bottom in the principal or trunk draws. Proceeding down a series of these draws, from twig to branch, from branch to limb, and thence to trunk, so to speak, one begins to find, where the inclination of the surface reaches an angle of, say, 20°, a succession of semilunar steps or depressions in the bottom of the draw. These are as sharply cut as though done with a spade. The first ones present a vertical, semicircular riser of probably not more than 2 or 3 inches in height. These depressions increase in depth, as the angle of inclination of surface increases and the draw narrows and becomes more channel-like, and assume a more circular form, inclosing a bowl-shaped basin, which has been hollowed out by the descent of torrents resulting from a shower of rain or from the melting of snows which have drifted into the draws. Still further down, these circular depressions become more and more elongated until, near the confluence of two or more branch draws, they become long, narrow slits in the grassy bottom, opening clean down to the underlying sand strata. After a rain, all the cup like erosions will be found filled with water which is finding its way down through the substrata. In some cases, by the gradual dissolving and washing out of soluble portions of the soil, the bottom of such a cup or depression will cave in until a well-like opening is formed. Through such holes as these, and through the above-described gashes in the lower portions of the bed of the draw, storm waters find their way into the substrata of sand and gravel with almost as much readiness as though pouring through a sieve.

Systems of these draws will be found leading into a river of the plains, very numerously, throughout at least the upper third of its length. Whenever such a depth of channel has been reached as to cut through the water-bearing grit, elsewhere described, the stream will have a hard, impervious bed, and springs will be found at frequent intervals, both in the principal channel and at short distances up the branch draws, from which there pours a steady flow of water, sometimes in very considerable volume. This section of such a stream enjoys a perennial flow of water. Further down, where beds of sand and gravel have been deposited, through torrential agency, the water often disappears from view, except during brief periods of flood, as already explained.

The accompanying diagrammatic longitudinal section (Fig. 3) illustrates the characteristics of the foregoing described portion of a river of the plains. At the point where the deepening of the channel cuts through the water-bearing strata (H) a stream of water appears, and in tributary draws springs will be found (as at S. S. S.) near by the main stream and nearly on a level with it, or perhaps further away and higher above the bed of the stream, according to the location of the stratum which supplies the flow. In some cases a spring, as at Ś, bursts out high up the side of the bank or of a distant slope.

Such springs appear wherever "the grit" has been cut through, and are numbered by thousands, stretching in a broad band from the northwestern corner of Nebraska, curving southward across Kansas, between the ninety-ninth and one hundredth meridians, and continuing across what was formerly called the "Neutral Strip" into Texas. They vary in volume from the almost unnoticeable "seep" on the hillside to the broad gush of a stream large enough to run a large flouring mill, and exhibit a great variety of interesting characteristics. One is spoken of in Scotts Bluff County, Nebr., which gushes out of a bluff 500 feet above the bed of the stream into which it flows. Another sends up so large a stream through a fissure in the bed of a stream that its flow makes a plainly visible ridge in the water.

The location of some of these springs upon hillsides would indicate that the flow of some of them could be increased by widening the outlets. This has, as a matter of fact, been done in several instances. One of the most striking is related by Hon. T. M. Haun, of Hodgeman County, Kans. Having observed that a spot of ground some 40 feet above the bed of Pawnee Creek, in that county, always showed dampness, himself and several others tried the experiment of digging away the overlapping layer of marl and were gratified by securing a flowing spring, discharging a stream equal to that from a 2-inch pipe. At last report, this flow continued without diminution, and it was thought that it might be increased by further digging.

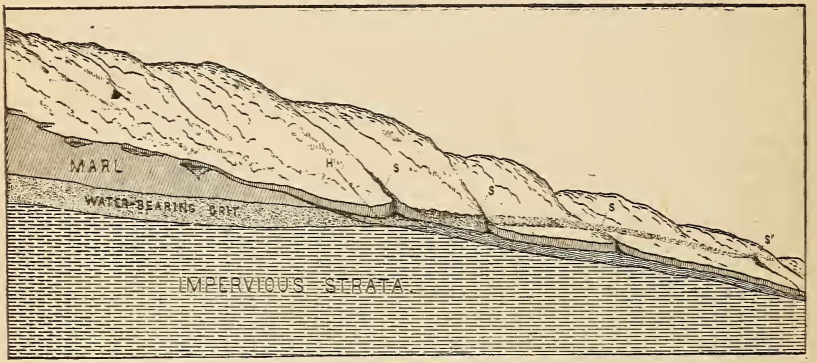

FIG. 3.—Origin and tributaries of Rivers of the Plains.

## THE NEED OF IRRIGATION.

It has long been accepted as a settled fact that any one who would undertake to practice agriculture in the foothills on this side of the "Rockies" and eastward, say to the one hundred and third meridian at least, must necessarily employ artificial watering to produce crops. It is a demonstrated and undeniable fact that, throughout every portion of the territory under consideration, irrigation is so valuable an aid to agriculture that the farmer will be most abundantly repaid for any reasonable expense and effort to obtain it; but, upon what meridian, as progress is made westward, the valuable adjunct becomes a positive necessity is a question upon which there is much difference of opinion, and for very good reasons. There are so many things to be taken into consideration in forming or expressing an opinion upon the point, and so many standpoints from which the question may be viewed, that only the most careful study and the broadest experience will enable one to arrive at a correct conclusion.

For my own part I am disposed to name the ninety-ninth meridian as the present eastern limit of the practical necessity of irrigation, Ten years ago it should have been located at least as far east as the ninety-eighth. Ten years hence it may have reached the one hundred and first, or even further westward.

In order to be clear it is, perhaps, necessary to make a distinction between the *absolute* and the *practical* necessity of irrigation upon these plains. In speaking and writing upon this subject for some years past, in a general way as well as in official reports, I have been accustomed to speak of irrigation as absolutely necessary to the successful general practice of agriculture in the territory under consideration. All experience, all obtainable facts, and all visible manifestations justified the use of the term in the sense intended; but I have been taken to task now and then as overstating the importance of irrigation to this region and find some explanation, and perhaps a qualification of terms, necessary to prevent a misunderstanding of facts. I do not wish to be understood as taking the position that the practice of irrigation is an absolute necessity in every season and in every individual instance in western Nebraska and western Kansas. As a matter of fact, not only is it not proven an absolute necessity in every detail, as to the two portions of territory named, but it is no more possible to demonstrate that it is so as regards any part of the Plains country as far west as Denver. In explanation of this statement the following facts are cited:

At Dodge City, Kans., upon the one hundredth meridian, is an experimental forestry station where timber-culture experiments are carried on by the State. The ground occupied is a high, round-topped knoll containing 100 acres, not only above the reach of irrigation from any source (except by pumping the water), but exposed to every "Kansas zephyr" that moves across the unobstructing plains. Here the superintendent has grown all sorts of native forest trees known to the latitude of the station, and in as thrifty and unbroken rows as ever graced an Illinois cornfield. In the unusually dry year of 1889, he grew 100 acres of seedling trees, including such varieties as walnut, ash, hickory, oak, chestnut, black locust, honey locust, soft and hard maple, cottonwood, ailanthus, catalpa, etc., without the loss of a tree from drought and with scarcely a curling leaf when the warm, dry winds blew for days at a time. His ground had been deeply plowed and thoroughly prepared, and the tract was thoroughly cultivated thirteen times in the course of the season, the soil being kept as clean and as finely pulverized as that of the best kept garden.

In the northwest corner of Stevens County, Kans., is a scope of country settled by well-to-do Kentuckians who went about the business of subduing the desert in an unusually energetic and thorough manner, and there may be seen to-day thrifty groves of young trees and young orchards in bearing. The settlement is 40 miles from the nearest irrigating canal. No irrigation was attempted. This spot is a few miles west of the 101st meridian.

Some 6 or 8 miles west of the one hundred and third meridian, near the south line of Arapahoe County, Colorado, is the little village of Thurman. Surrounding it is a settlement of German-Americans from Ohio. They have occupied their land for four years and say they are farming successfully. Less successful neighbors a few miles distant will assure the traveler that the people of that colony are living and farming upon the means they brought with them from the East. But the well-tilled fields, the tidy farm buildings, the occasional cribs of corn, and stacks of roughness show that they have succeeded far beyond the average of the new settlers in that locality. They have no means of irrigating, and their land is a part of the same marly plain, with a sparse covering of buffalo and gramma grasses, which may be seen in all other portions of the division, with nothing, so far as may be observed by the eye, different from the land elsewhere.

In the eastern suburbs of the city of Denver, almost upon the one hundred and fifth meridian, and at an elevation of 5,000 feet, the proprietors of an eastern nursery planted a large tract to fruit trees, four years ago, depending upon a means of water supply for irrigation which failed at a critical time after the trees were planted, and the proprietors were compelled to do the best they could without irrigation. Thorough and persistent cultivation was resorted to, and with such success that there was no further attempt made to irrigate, and there is to-day a magnificent young orchard of bearing fruit trees at the one hundred and fifth meridian, upon the western extreme of the "Great American Desert," where the average annual rainfall for a period of eighteen years has been but 14.46 inches.

Now, inasmuch as "what man has done man can do"—if he will do it in the same way—it follows, from the foregoing examples, that it must be *possible* to grow both crops and trees upon the Great Plans, at *some* cost and at least at certain times, without the aid of irrigation. And a great many striking individual proofs of the fact might be cited, in addition to those given. Hence, it must be conceded, as I have already conceded, that it is not literally and strictly correct to say that irrigation is *absolutely* necessary in all seasons to the production of trees and crops upon the plains. And I never have so stated, but have said that irrigation was necessary to the *general*, *successful*, and *continued* development of agriculture upon the Plains, *under existing conditions*. As it must be admitted, considering the cases of successful dry farming cited, and regarding also the fact that there are certain dry-weather crops which may be grown successfully most years (as millet, rice corn, broom corn, etc.,) without resort to artificial watering, it is doubtless better to be literal and exact in language and denominate irrigation simply a *practical* necessity upon the Great Plains, though it is making a distinction in terms which amounts to little or nothing in effect.

If a certain combination of facts invariably produces a certain result, it can make little difference what adjective shall be used to describe the combination. If the result is to be changed it must be done by altering the state of facts. The importance of this particularity to the subject under examination will, I think, be appreciated upon a comprehensive view of the matter.

The Great Plains possessed, when white men first beheld them, the same soil as now, under the same sunny skies, and with substantially the same climate. If it could have been brought about that the whole of this region could have been settled in a single season, or two or three, by a class of people each one of whom should have been possessed of the discernment, training, natural aptitude, and knowledge of what he wished to do, which characterize the superintendent of the forestry station referred to, each able and willing to practice the industry and frugality of the Germans of the Thurman Colony, each having the surplus means with which to provide all needful buildings, seeds, plants, and farming tools to emulate the Kentucky settlers in Stevens County, and to enable them to continue work three or four years, if need be, at large expense, before any returns could begin, as in the case of the nurserymen who have grown the unirrigated orchards at Denver, then there can be little doubt that the sudden cessation of sweeping prairie fires, the widespread planting of groves and orchards and belts of timber as windbreaks, the upturning and thorough cultivation of a large proportion of the surface soil on every habitable quarter section, and the covering of millions of acres of land, theretofore almost as bare and as hard as a slate roof, with green, luxuriant, and succulent vegetation would have worked an almost miraculous change; the desert would have blossomed and borne fruit often enough, without the aid of irrigation, to make the Plains as a whole habitable after a fashion. That is, if people having the mental attainments, the physical energy, and the financial accumulations of the best, shrewdest, and wealthiest farmers of the East could have been brought simultaneously by the hundred thousand and induced to live in dug-outs and sod houses on unshaded prairies until dwellings could be erected, the whole area of the wild prairie broken out and cultivated, timber grown, schoolhouses and churches built, they would then have been in shape to begin to make a living as soon as railroads should become sufficiently numerous to transport supplies to them and crops to the markets at living rates, provided they had all been able to promptly lay aside former experience, the methods previously acquired, and to take up the culture of new crops in new ways—a new sort of life, without the aid of teacher or illustrative example.

Or, if settlement and occupation had taken place by slow degrees, the frontier advancing but a few miles each year, so that the settler upon new land should have had the advantages of the examples, close at hand, of successful methods of operation; instruction as to successful varieties of crops, and how to produce and utilize them; local markets; adequate means of transportation for his products and supplies, at living rates; and openings to labor for wages, to sustain himself through the uncertain and often unproductive two or three years required to subdue a new piece of land; then the advance of settlement might have been made without disadvantage to the pioneer; there would have been no retrogression to speak of; and when the limit had been reached, beyond which it was not safe to venture to farm without the aid of irrigation, further advance would have been made only after an adequate water supply had been assured; but emigration has moved in periodic waves and large areas of new land have been covered with people in short spaces of time.

Not more than thirty-five years ago emigrants who were settling immediately west of the Missouri River were gravely, earnestly, and no doubt honestly, assured by persons "who had been all over that country" and "knew all about it by personal observation," that nothing whatever could be produced west of the Missouri River, except "Indians, buffalo, grasshoppers, and hot winds." At that time the Missouri River was the eastern border of the desert. On the other hand, the boundary of practicable settlement has been steadily shouldered westward by the pioneer corps of the advancing army of civilization so far, so rapidly, and at times with such apparent success that the hasty and enthusiastic have rushed to the other extreme by accepting a favorable season or succession of seasons as a demonstration of decisive victory of man over nature and have declared the desert driven into the fastnesses of the mountains and imprisoned there. But they have found that, while capturing an enemy's outposts may be an easy task, driving him from his intrenchments may be quite another matter.

While every new portion of the unsettled domain, from Plymouth Rock westward, has presented some new sort of obstacle to be overcome, out of the fact that each has been, in time, grappled with and removed has apparently grown the idea that courage and pushing forward would win under all circumstances. People have had warnings of one sort and another not to venture upon the dry plains adjacent to the Rocky Mountains, but there was nothing authoritative nor general. The great body of emigrants in their search for homes have looked upon the land in the beauty of springtime, when it seemed as fair, as rich, and as full of promise as any land under the sun. There was nothing that the prospective settler could perceive which he felt justified in accepting as a warning that all was not what it seemed. At the United States land offices in and for the region visited, he found officers ready to accept his filings upon precisely the same terms as regulated the taking of land in Iowa, Missouri, and Arkansas. The same fees, the same length of occupation and amount of improvement were required, and the same price per acre demanded if he chose to preëmpt, as there had been in Illinois, or Wisconsin, or Indiana.

The conclusion naturally followed that, by doing as the settlers in Iowa and Missouri and as those in eastern and central Kansas and Nebraska had done, those who ventured out to the western boundaries of these States and beyond could achieve the same success. No account was taken of the material difference in annual precipitation nor of the midsummer drought, because few settlers were aware of the facts. The country was reported to be dry, but it was hoped, stated, and believed that the rainfall would increase with the settlement of the land. A few people realized that there must be a line somewhere east of the mountains beyond which it would not be safe to go, except under the protection of the irrigating ditch; but that line was always estimated to be somewhere beyond the "next county" at the least. Now the people who, in search of homes, entered upon these lands in good faith unite in saying that if the Government had made known the deficiencies, as to climate, and offered the land for settlement on terms in accordance with such deficiencies, they would have been fully informed in the premises and could not have suffered so great losses.

The Plains country has been inundated by such human floods more than once. Thus one of the conditions of successful settlement was met. There was sufficient density of population. But the very large majority of those who sought for new homes were comparatively poor people. They had not the resources to enable them to labor on for two or three years with scanty returns for their labor; they were under the necessity of earning a livelihood as they went along. Not one in a hundred understood the new conditions under which he found himself located. Some attempted to ascertain with what new problems they had to deal and to adapt themselves thereto, but most went to work according to the methods they had learned to depend upon in their former localities—it was all they could do, they had neither teacher nor illustrative example of anything different—and depended upon growing the same crops as of old and in the same way, except that less energy was shown and they had not the same faith in results. This was perfectly natural. It is but natural that when a great many men find themselves suddenly thrown into the midst of new and untried conditions, with no demonstration of results to stimulate them to action, instead of immediately laying out all their means in seed and labor to cultivate and crop new land, they should try planting a little to "see how things turn out;" whatever unfavorable reports concerning the country the settlers may have had, while not sufficient to keep them back from attempting settlement, adding largely to the natural feeling of uncertainty and tending toward more desultory, less hopeful, and more easily discouraged efforts. The cost of everything which has to be bought under such conditions is always unduly heavy, and a newly settled country, having no established manufacturing industries, all the inhabitants being necessarily producers, situated far from industrial centers, and with scant and costly means of transportation, must necessarily be without local markets and out of reach of foreign.

It has been asserted by certain classes of people for years past that the great body of the settlers upon the semi-arid lands were "lazy, trifling, unenterprising, town-lot speculators, boomers," etc. It has been alleged that they went upon their lands merely to stake out town lots, to fight over county seats, or to secure money on their claims by mortgage, immediately removing after this purpose was accomplished. Having known intimately the people, and witnessed their efforts to subdue these wild lands, having experienced the discomforts, the privation and reverses incident to the difficulties encountered, I wish to take this occasion to refute the slanderous statements so glibly made, and to correct the false impressions which have been thereby spread abroad. There has been, among the mass of people settling upon the semi-arid lands, a certain admixture of the idle, the speculative, and the vicious, as there always is among so large a number of people; but the great majority of the settlers upon the semi-arid lands in the past ten years were enterprising, ambitious, hopeful, energetic, honest home-seekers. They entered their lands in good faith and made more than ordinary efforts to secure permanent homes for themselves. A large proportion made preëmption or commutation proof upon their land and mortgaged it only because it had become apparent that they could not maintain themselves upon it during the five years necessary to secure title under the homestead law, and because they were compelled to secure money to maintain their families. In a few instances, through the dishonesty of local agents loaning on commission, settlers were induced to take so large a loan as to make the transaction a virtual sale; but in a large majority of cases, loans were secured in good faith, and when the settler afterward removed from the land it was because he was compelled to go elsewhere to make a living and his removal was intended to be only temporary.

The struggle between improvement and desolation, with the great plains as a battlefield, has been one in which the contestants have each prevailed and retreated by turns. As two fierce antagonists struggle back and forth over disputed ground, one conquering, the other beaten, sorely pressed, and almost despairing, only to gather anew sudden strength and courage and bear back his enemy until the two have changed positions, so the resolute settler has battled with stubborn and untoward conditions for the possession of the land. Wave after wave of immigration has rolled across the zone of uncertain territory lying between the unquestionably arid region and that sufficiently humid to make farming something more than an annual experiment. When there has been a brief succession of favorable seasons, the settlers have pushed forward eagerly, hopefully, and with the heedless ignorance of the difficulties to be encountered which was natural under such circumstances. After a brief battle against overpowering odds, they have been forced to give up, for a time, much of the ground gained; but the struggle has been renewed over and over. Each succeeding wave has rolled beyond the line reached by its predecessor and has left valuable wreckage and something more, and there has consequently been a large net gain in the direction of the final reclamation of the semi-arid region; but the cost is loss of time and labor, in lost homes and hearts made sore and discouraged by disappointment, has been enormous.

Now those who have, despite all untoward conditions, managed to maintain their foothold upon these semi-arid lands, and in so doing have seen so many fail, assert that there ought to be a change in such methods of reclaiming these lands; that as it is manifestly bad policy to permit the attack of a fort by allowing masses of men to hurl themselves against a strong, cannon-guarded wall, when the wall may be overthrown with certainty, celerity, and safety to the attacking party, by undermining it, so it is certainly not good public policy to permit men and their families to attempt to make homes on these lands in the uninformed, haphazard way which has thus far obtained, at such expense of fruitless labor and broken hopes, when it is so easily possible to remove the elements of ignorance and uncertainty and thus prevent loss. It would doubtless be conservative to estimate that this region, averaging the whole area, has been thrice settled and depopulated. The whole has been sown with gold and doubly watered with the sweat of toil and the tears of disappointment. There is not an acre in the Plains region but has already been dearly and doubly paid for.

All that has been borne and suffered of privation and loss has but barely made clear the fact that, while there are many other things which may be done which will exert a powerful influence toward the final triumph of those who seek to utilize the Plains for agricultural purposes, a supply of water for use in irrigating is a necessity to supplement the rainfall over a large area immediately east of the Rocky Mountains. This fact will possibly, nay probably, be but temporarily noted at the present stage of popular information—or lack of information—upon the matter in hand. There never has been wanting, at any stage of settlement, prophets of evil whose voices have been heard, even in the flush of apparent victory, ominously warning that such triumph was but temporary; that "the desert will return to claim its own," and that only final disaster could await those who should persist in attempting to wrest concessions from nature; that to attempt to go counter to the fixed conditions found existing upon the arid Plains could only end in defeat and loss to the foolhardy, adventurous settler. Notwithstanding the fact that the warnings have always proven, in part at least, well founded, they have never been of appreciable benefit to those warned. The utterers of warnings have always been considered "croakers"—so long as it rained—and when it grew dry and the hot winds blew, "I told you so" never eased a single disappointment or saved a dollar of loss; and no sooner has one set of settlers "dried up and blown away" than a succession of apparently favorable seasons has tempted a new immigration. The semi-arid region has been, and unless proper efforts shall be made to prevent will still be, an absorbent of wealth and energy; a famine-breeding, heart-breaking zone; a mirage to tempt men to ruin; and the question is asked whether it should not either be made certainly habitable or settlement there, under ordinary conditions, prevented?

On the other hand, it has unquestionably been demonstrated that if the Great Plains can be taken from the category of desert lands and become irrigated lands they must then become a center of wealth, production, and safety, instead of a menace, a constant absorbent of labor and wealth. The largeness of area of excellent land, the advantages of a central situation as regards the rest of the country, the salubrious climate, and other advantages which have already been noted, must impress the most casual observer with the fact that, when that which is lacking shall have been supplied, the Great Plains will become capable of supporting many people, adding largely to the common wealth and to the number of American homes, those safeguards of the nation.

## THE MEANS OF RECLAMATION.

I have heretofore stated in my reports to this Department that all of the arable land of the Great Plains region may be, and ultimately undoubtedly will be, reclaimed and made habitable. I will take occasion here to repeat this statement, and to add that an exceptionally dense and prosperous population may be supported thereon. This conclusion will not be charged to over-enthusiasm by anyone who understands how little there has been manifest in the way of development or improvement in this region in the past three or four years which could inspire enthusiasm or even hope. But it is a fact that wherever irrigation has been possible and has been employed upon the lands of this division, whether arid or semi-arid, and even under unfavorable conditions and by the untaught and the injudicious, while there have been reverses and complaints, there has also been constant growth, marvelous improvement; and settlers, whether from New England, from the South, or from the Mississippi Valley, have managed to do more than "hold their own." They have prospered. Such prosperity and growth, in far more marked degree, may be extended to all the Plains country if a large proportion of it may be irrigated; and it may be accomplished by the classes of people who go home-seeking, for such have succeeded, even under all the disadvantages encountered in a new country and in a business new to them, and where the most courageous and energetic have failed without it. It follows, then, that if the predicted result is to be brought about with reasonable speed and at reasonable cost, general irrigation of this region must be possible. The opinion that it is possible and that it will be accomplished is based upon three facts:

1. The great retentiveness of moisture which characterizes the marly soil of the Plains. This is a characteristic which is well known to all who have become acquainted with the facts and conditions existing throughout this region. There is probably no soil in any part of the United States which will longer retain and make available for the use of growing plants the moisture which it receives than will the ashy-colored but highly fertile Tertiary marl heretofore described as constituting by far the greater portion of the soil of this division.

2. The fact that there is so large an annual precipitation throughout the region, and that so large a proportion of it falls in the growing season, between April 1 and September 1.

3. The demonstrated fact that there are stores of accessible underground waters underlying and underflowing the entire Plains region.

The means by which the reclamation of the semi-arid lands may be brought about may be classified as follows:

1. The recovery of underground waters by gravity, by mechanical means, and by artesian wells.

2. The storage and conservation of surface and other waters. This involves not only the construction of reservoirs, but the protection and extension of forests.

3. The greatest economy and care in the use of the water supplies. This involves the gradual increase of the duty of water: (*a*) by the gradual saturation of the soil; (*b*) by experience in the use of water in its application to the soil; (*c*) by the adoption of the most highly economical methods of use; (*d*) by growing crops adapted to the economy of moisture; (*e*) by largely increased thoroughness of cultivation.

A most important element in the work of reclamation, the value of which has not been generally understood and is rarely estimated highly enough, is the prevention of the recurrence of sweeping prairie fires.

These are not only most destructive to property and sometimes to human life, but, by denuding the surface of the ground and exposing the latter to the action of the sun's rays and to the impact of warm and desiccating winds, render it not only very dry, but also exceedingly hard, so that not only is plant life destroyed, but the ground is reduced to such a condition as to most readily turn aside and get rid of whatever rain may fall upon it, for a long period after it has been so denuded. When such fires have been prevented for a series of years, on the barest portions of the Plains, the growth of grasses and other vegetation has thickened and increased wonderfully. This increased growth of vegetation catches the winter snows, retains the summer rains, retards evaporation, aids in the formation of dew, tempers the heat, mellows the soil, and goes far toward rendering possible the growth of trees and crops on an extended scale. The prevention of such prairie fires is a plain necessity and has already proven not the least of the agencies by which the semi-arid region may be benefited.

I feel that it is a duty to call attention once more to the fact that whatever development shall take place, if it is to be of benefit to present settlers and to small landowners, should be pushed forward with promptness and great vigor. It needs nothing more than the suggestion to make it clear that working people with families to support and educate—and often with accumulations of debt instead of surplus property—are not prepared to await for years the changes which are necessary to convert desert lands into farms.

The fact has been dwelt upon that thousands of people who settled on the semi-arid lands in the past few years have been compelled by continued crop failures and other stress of circumstances to remove temporarily to more humid regions. These temporary removals have, in certain proportion, already become permanent, and unless something may be done in a comprehensive and systematic way to supply the means of irrigation, still a large proportion of those who, through much privation and great labor, have earned the right to retain their homes upon these lands, and richly deserve to do so, must suffer the total loss of all their labor and their investments of Government rights, time, and money. The construction of such irrigation works as will be necessary to supply the water needed for irrigation of these lands, it is believed by the people remaining, would furnish sufficient employment to those of the inhabitants needing employment as a means of subsistence, to afford all necessary temporary relief; and that the confidence and increase of values born of such construction would supply all the rest that is necessary to place the people upon a safe footing. Such a work as would be a benefit to the people and accomplish the widest and permanent development of the country must of necessity be upon a large scale and must be systematic, thorough, judicious, and well balanced. While a careful weighing of facts gathered in the study of this subject has demonstrated that the whole Plains region may be reclaimed, it does not appear that there is any safe margin for waste or mistakes. In fact it is clear that this great result may be fully accomplished in reasonable time and at fair expense only through intelligent system, rigid economy of means, and discriminating care. Private capital, in immense sums, must eventually be employed in the work; but such are the popular interests affected and the interstate questions involved that the opinion is entertained by those most conversant with the situation that the General Government should first outline the work to be done, and also make such regulations as will require that all which shall be done, whether by individuals, by States, by municipalities, or by corporations, shall be part and parcel of a systematic whole; that the equities of all concerned shall be safely protected and a safe, certain, and plain legal method of settling all interstate questions which may arise be carefully provided.

The opinion prevails among the common people throughout the division that the Government should cause a few practical demonstrations of the existence, availability, and economical conservation of water supplies, so that private capital may be induced to invest in the work of development to the fullest extent and upon an assured footing. This opinion is founded upon the fact that not only have the settlers upon such lands paid for the same, into the United States Treasury, very large sums of money—this alone constituting, as they believe, a sufficient reason for the active intervention of the Government in matters of irrigation development for their benefit—but, further, such action upon the part of the General Government as would take the lead in the provision of general systems of irrigation works would confirm to the National Government, fully and unquestionably, the right to make such regulations for their use as will inure most largely to the benefit of the people. And such are the intermingling, interdependent interests of individuals, communities and States, in the general development of the means of irrigation upon the Great Plains, that the regulation of such works and the settlement of the grave questions arising from the use of the same may proceed, it is believed, only from the National Government; that there is no other possible source of such regulation. If matters continue as at present, there is great danger, first, of delay in inducing capital to undertake the work of development; secondly, and continuing the doing of such crude, wasteful, and unintelligent work, which will cost enormously more than it ought; of the establishment of obstructive and wasteful vested rights, which will greatly delay if not wholly prevent much proper development; and of the aggrandizement and complication of interstate difficulties which may now be easily removed. And all these things will be certainly and ruinously wasteful of time, money and labor, and the equitable rights of the people.

I have referred in general terms to the means of reclamation. It is necessary, in order to give to some features the full examination and discussion required, in furtherance of the purposes of this investigation, to pass over others briefly. The careful conservation, by means of storage reservoirs, of storm and flood waters and of waters which now run to waste through fall, winter, and spring months, the protection and extension of forest growth, the prevention of prairie fires, and the employment of the most thorough methods of cultivation upon the broadest scale are all necessary to the reclamation of the Plains region. Not one of these agencies can be dispensed with, but all must be considered in conjunction with the matter of the recovery and utilization of the subwaters, which is more important than any and all the rest only because it is as the keystone to the arch, without which all the rest would be of comparatively small value. To pass over these important subjects with great brevity, therefore, is not to be construed as underestimating their importance, but is rendered necessary by the time and space required in the discussion of the principal subject of this investigation.

## ARTESIAN WELLS.

This source of water supply must, in the nature of things, remain an insignificant factor in the problem of arid land reclamation so far as concerns this division. There is but one artesian area in the division the waters of which are as yet applied to irrigation uses, and this in a small way. In the Crooked Creek Valley, in Meade County, Kans., are about one hundred flowing wells. The water is obtained by boring to a depth of from 39 to 137 feet at an average cost per well of but $20. This is the estimate of Hon. T. J. Palmer, of Meade Center, in the artesian district. The wells have a weak flow, the strongest one producing but 66 gallons per minute and the others ranging down as low as a couple of gallons. This artesian area is caused by the doubling back upon itself of the course of Crooked Creek, causing it to run across the course of the underflow, and the eastern bank of the stream, being composed of heavy masses of a more or less impermeable nature, dam up the underwaters so that, when an underlying stratum of impervious clay is penetrated by the boring tool, the water rises to a sufficient height to flow over the surface from such wells as are situated in the low portions of the valley. In wells upon the adjoining upland, water rises to about the same level as in the flowing wells of the valley lands, but the "head" is not sufficient to cause the water to rise to the surface. Such wells can not be had in that vicinity, except in the valley of the stream. The water supply, however, of those which do flow, coming as it does from the "sheet water," will undoubtedly be permanent. About 1,200 acres of land are now under irrigation from these wells.

A similar artesian area, though smaller, will probably be developed hereafter in the vicinity of what is known as the "Wagonbed Springs," in Stevens County, Kans., from the same causes which produce the Meade wells. The course of the Cimarron doubles back upon itself, crossing the course of the underflow and forming a sort of pocket, the eastern bank being of such a nature as to dam up the underwaters.

In Morton County, Kans., are two flowing wells, and in Hamilton County are five, the flow from which is too weak to render them of appreciable value for irrigation. Those at Coolidge, Hamilton County, average about 250 feet in depth. The two at Richfield, Morton County, are a little more than 600 feet deep. The water comes from the sandstone which underlies a large area to the west and south and which receives its waters largely from Bear Creek, and possibly similar sources, as hereafter described.

While other wells and other small areas of artesian water will doubtless be developed in the division, there is, at present, nothing to indicate that the supply of water from such sources, considering the cost of procuring the same, will be of appreciable value to the general irrigation of the lands of the division.

## THE "UNDERFLOW."

Since the beginnings of settlement of the Plains, people have been familiar with the fact that, throughout the whole region, excepting in isolated cases and in certain small areas, wells obtain their supply from what is popularly known as "sheet water," and that this has proven a copious and inexhaustible supply. Such wells uniformly penetrate a bed of water-bearing sand or gravel, or both, to a sufficient depth to insure a plentiful supply of water, but in a large majority of cases the bottom of the water-bearing stratum is not reached nor does the well digger succeed in ascertaining how deep it is. In most instances no effort is made to ascertain what may be the depth of such a stratum. An abundance of water assured, there would be no motive, other than curiosity, for pursuing investigation further, and few plainsmen could afford to spend much time or labor in the gratification of a mere desire to know an apparently useless fact, even if the desire were present.

The apparent uniformity of water level in such wells, however, in any cross section, and the uniform average depths from surface to water, in a broad plain having a pronounced subsidence in a given direction, show conclusively that what is known as "sheet water" must be suspended either in a succession of lake like beds, as illustrated in Figure 4, or must flow with some degree of current through an extensive underlying stratum of grit, as in Figure 5.

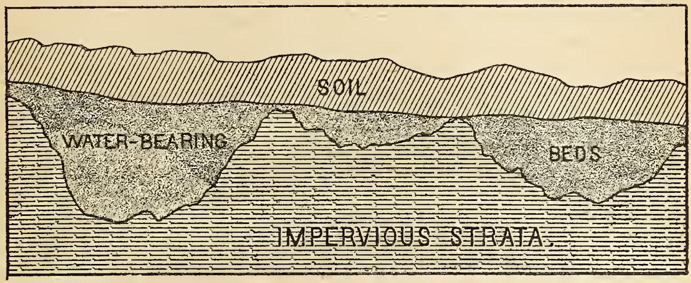

FIG. 4.—Diagram of water-bearing bed.

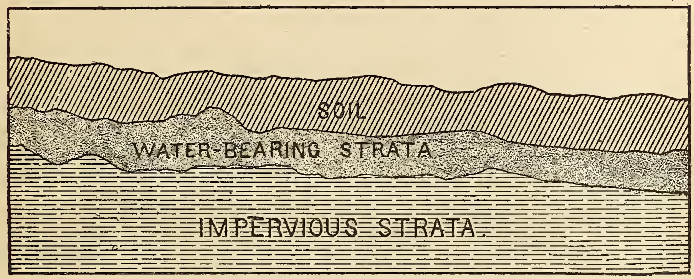

FIG. 5.—Diagram of strata.

That the latter condition obtains, at least locally, is apparent from the fact that all the larger streams and most of the small ones traversing the Plains from west to east flow over beds of water-bearing grit, ranging from a few feet to hundreds of feet in depth, and of unknown lateral extent. That there must be a current, however slight, throughout large portions of these sand beds, is evident upon the most cursory examination of the facts. The grit is not simply moist, but so full of water that a 1¼-inch pipe, with perforated point, driven into it to a depth of 2 or 3 feet, furnishes so free a supply of water that an ordinary pump with a cylinder 4 by 12 inches in size makes no apparent impression upon it, and it is not unusual to find a 4-inch bored well, penetrating the water-bearing medium from 8 to 10 feet, supplying water so freely that there is no perceptible effect upon the water level from watering 50 head of cattle, and even more, daily, in addition to the supply required for the ordinary use of a family.

The great deposits of grit contain, in places, beds of sand so fine and dense that the passage of water through them is necessarily slow. But, to counterbalance these, there are alternating deposits of gravel so coarse that water flows through them with great freedom, and the rule is a mixture of sands and gravels of varying degrees of fineness and coarseness, making a medium which permits a very free flow. Given a deposit of this sort, several hundred miles long, from 5 to 300 feet in depth and many miles wide, the whole saturated with water and having a slant throughout its whole length of 5 to 15 feet per mile, and there needs no argument nor further evidence to demonstrate to the most unscientific that there must be a constant movement of the water towards the lower end of the vast bed, unless it were inclosed, top, bottom, sides and lower end, by some impervious substance so that the water would be confined as though in a jar. The Arkansas, Platt, and Canadian valleys are illustrations of such deposits. That there must be means of egress of the water at the lower extremes of these immense beds, wherever those extremes may be, is apparent, since there is abundant means of escape at the surface if there were none below. Some of it is undoubtedly forced into the channels of such streams towards the mouth by the accumulation of the water in the more nearly level portions of the deposits, thus contributing to the large perennial flow always found there. The channels of such streams are simply uncovered and slightly eroded portions of the vastly wider underlying sand bed, and the water flowing therein at low stages is but an escaping portion of the underflow. Thus there may be seen slender streams of water coursing down these sandy channels, varying in width and depth without regard to any visible source of supply or cause of depletion, in some places a deep and broad stream and again none at all. The explanations of these manifestations being fully stated elsewhere, need not be repeated here.

Further evidence of the existence of a general movement of these underwaters may be found in the more or less plainly apparent currents in open wells in various portions of the Plains. In some cases the flow of the water may be plainly seen. In others, the existence of a current is indicated only by the fact that bits of wood, paper, straw, etc., blown into the wells, gather closely against the eastern wall in the course of a few hours.

Mr. John A. Stevens, of Garden City, Kans., in excavating on second bottom or second bench land to lay the foundation for a large building, reached the water level and the inflow of the water from the north and west and its course toward the southeast were plainly apparent.

Mr. Gus. Koehler, of Grand Island, Nebr., has artificial ponds for ice and fish, made by simply scraping away the surface soil and enough of the underlying sand (in this case very fine and dense) to make basins in the subwater, and the inflow of water, as in the above mentioned case, is from the north and west.

Still further evidence of constant movement in these underwaters may be found in the great aggregate discharge of the springs which pour out along the exposed edges of the "mortar beds" or "Tertiary grit." These discharge, constantly and with steadiness of volume, immense quantities of water, much of which little more than sees the light before it is again lost to view in the sand. To maintain so large an aggregate flow, there must be a constant movement of large quantities of water through the subterranean beds of grit.

Again, within the past twelve years a number of so called "sunk wells" have been formed by the sudden caving in of a portion of the surface, in different parts of the Plains, disclosing deep pools of water below a theretofore dry and unbroken surface, showing that soluble matter had gradually been dissolved out and carried away from beneath in large quantities. One such pool was formed near Meade, in Meade County, Kans., in 1880. Others are to be found in Grant County, Kans., which are of a recent formation, while there are many more in different parts of the division, which were formed long ago.

Again, there are known to be many and large subterranean streams throughout the region of country to the southeastward, even to the Atlantic coast, and interesting stories are told of immense fresh-water springs off the South Atlantic coast and in the Gulf of Mexico, which send up from beneath such floods of water that it may be dipped up fresh and drinkable from the midst of the sea. An inquiry some time ago respecting these phenomena met the following reply:

U. S. Coast and Geodetic Survey,
*Washington, D. C., July 7, 1890.*

Sir: Referring to your inquiry of July 3 about submarine springs of fresh water which are of sufficient volume to make themselves visible at the surface by actually furnishing fresh water, I have to say that there is one shown on our original sheet No. 1267b, about 3 miles off the coast abreast of St. Augustine; this has been officially located and is beyond dispute. We have only had rumors concerning a similar spring near the mouth of the Mississippi River; our surveying parties have never happened to find it, and we have never made an especial search for this particular phenomenon. It has been so often casually referred to, however, that it would be very desirable to have an especial examination for it, provided the funds could be furnished to defray the expense.

Yours respectfully,

T. C. Mendenhall,
*Superintendent.*

Mr. J. W. Gregory,
*Division Field Agent Artesian Wells Investigation,*
*Department of Agriculture, Washington, D. C.*

It may be said that the citation of ocean springs, in the discussion of the underflow of the Great Plains, is reaching out to something quite remote. There can, of course, be nothing more than a speculative connection between the two; but it is interesting to consider that there must be a constant and abundant supply of water from a source sufficiently elevated to afford a high pressure to maintain such springs as those spoken of. Besides, I have met with an incident in this investigation which at least adds interest to the speculation. In Mitchell County, Kans., about latitude 39° 30′, longitude 98° 30′, is situated a curious spring, which the Indians held in great awe and esteem, giving it the name of the "Great Spirit Spring." The following extract from correspondence contains the interesting point referred to. Hon. E. D. Crafts, Downs, Kans., says:

* * * In regard to Great Spirit Spring, while the flow is small, the water stands in large pools, several feet elevation above the surrounding country. * * * Mr. Piper, who lives near the spring, says that the water fell 2 feet 9 inches at the time of the Charleston earthquake and did not fill up again for two or three weeks.

This reference is given simply for the suggestion which it affords to the thoughtful mind that could the hidden ways of the subterranean streams be surveyed and mapped, there would doubtless be disclosed many astonishing variations from the drainage of the surface waters.

## ITS EXTENT.

Plainsmen all speak of the "sheet water" as something to be found almost everywhere under this region and as being in inexhaustible supply. The following extracts from correspondence indicate how widely it is found and how it is estimated by the people:

Daniel Applegate, residing in the western part of "No Man's Land"

The valley of this river (the Cimarron) is from 1 to 2 miles wide, with an under current of water—a steady flow. The depth of the under current is unknown to me, but I know there is plenty of water here.

B. F. Babcock says, concerning underflow water in Wichita County, Kans.:

I started a short ditch about 4½ miles southwest of Leoti, on the White Woman Creek. We struck the bed of the creek at a point where it was as dry as a board, but before we had punctured 6 feet we had a fine flow of clear water, which has kept up for more than five weeks. There is not enough pressure in the White Woman Valley to bring water to the surface by boring, but the underflow exists, in my opinion, if not in inexhaustible quantities, at least in volume sufficient for practical irrigation.

W. R. Gibson, Arlington, Colo.:

Above the shale here exists a lake of water about 35 miles long and from 2 to 10 miles wide, with a probable average depth of 15 feet in sand, at many places coming to the surface in flowing springs. It has an average depth from the surface of 15 feet. The water in this lake seems to be flowing southward along the course of Adobe Creek, in ranges 54 and 55 west and through townships 17 to 22, inclusive.

C. H. Longstreth, Lakin, Kearney County, Kans.:

We are located on an ocean of water, which can easily be made to flow to the surface perpetually in sufficient quantities to flood the whole country at any and all times of the year.

Hon. Ben. C. Rich, Trego County, Kans.:

The sheet water is invariably below the conglomerate (except the bottom lands where there is no conglomerate) and above the chalk rock, and so far as I can learn, is coextensive with the county. Springs are numerous in all parts of the county, but more numerous on or near the summit of the divide, say within a mile or two of the summit and then again crop out near the stream. In the space between, water can be had only from wells ranging from a few feet to 114 feet; on the Union Pacific Railroad divide, between Big Creek and the Saline River, from 60 to 114 feet; on the divide and slope to the Smoky River, from 12 to 40 feet, with a few exceptions where they have to go into the rock. Most of our springs are permanent, with a uniform flow through summer and winter, wet or dry.

Judge J. A. Gardner, Pratt, Kans.:

There is a lake of water underlying this entire county from 10 to 90 feet below the surface.

J. U. Shade, live-stock agent Chicago, Rock Island and Pacific Railroad, Liberal, Seward County, Kans.:

Concerning the springs and underflow of water in the Neutral Strip, Oklahoma Territory, will say there are about five small streams headed by springs in the center and western portion of the strip, except a block of about 40 miles in the extreme western portion, which is dry, except the extreme north line through which the Cimarron River flows. All of the above mentioned small streams vary from 5 to 20 miles in length and empty into the Beaver River, which is an all-year stream, until it reaches the quicksand, about 30 miles west of the east line of the strip, where it usually disappears for several weeks in dry seasons. In the eastern portion there are several small streams headed by springs and they, like the Beaver, disappear when they reach the lowlands. Regarding the underflow, or sheet water, I have had several wells dug, and the depth varies from 20 to 90 feet, and the water is usually found in the quicksand and inexhaustible. At one of these wells at which we water cattle, which are driven from New Mexico and the Pan Handle of Texas to the railroad for shipment, I use a steam pump (well 80 feet deep), and during the summer of 1889 watered about 21,000 head of cattle and about 16,000 head of sheep. I mention this to give you an idea as to the extent or supply of water. This well is about 20 miles from any living stream of water and is situated in about the center of the strip east and west and about 7 miles from the north line. This is an exceptionably good well, but water has been found at all points where wells have been dug, in sufficient supply for a well-stocked farm.

J. F. Van Voorhis, Springfield, Seward County, Kans.:

One-half mile south of Fargo Springs, 3 miles from Springfield, may be found Eureka Springs, a slight depression in the valley near the river where, by digging 2 or 3 feet and sinking barrels, as formerly done, water rises to near the surface in apparently inexhaustible quantities. Small springs of seep water are found in several places along the Cimarron and undoubtedly have their source in the universal sheet water strata. The Cimarron River, which loses itself in the sand in southeast Grant

County, comes to the surface 4 miles east of Springfield. It increases in volume quite rapidly, and where it leaves the county line it has probably five times the amount of water which flows by old Fargo.

T. E. Ickes, Alexander, Rush County, Kans.:

The underflow in Walnut Valley is about 20 feet deep and inexhaustible.

W. H. Markham, P. M., Rexford, Kans.:

It is generally conceded that this whole slope is underlaid by great unfailing sheet or streams of water.

Judge J. W. O'Brian, Coldwater, Sherman County, Tex.:

Our sheet water is found here at from 140 to 160 feet on the flats and, when dug or bored, wells are made to give an unfailing supply. I think experiments with the underflow of the water courses would be very beneficial and would, in any place along the dry beds of these courses, give good flowing wells at a nominal cost.

C. Kelley, Stewart, Colo:

About 5 miles north of here is the stream called the Whitewoman. There is seldom any water to be seen in the stream, but water is found in abundance a few feet below the surface in its channel.

L. J. Carrington, C. E., Culbertson, Nebr.:

I do not know the lateral extent of the water-bearing strata in this vicinity, but all the wells in the divide have to be dug to about the same level and always get water. In some places they have to go as deep as 300 feet and strike the same bed of sand and gravel.

James Newall, Kimball County, Nebr.:

Lodge Pole Creek, a mountain stream, starts northwest of Cheyenne City, running through Kimball, Cheyenne, Deuel, and other counties. Part of the way it runs under ground. There are many springs along its banks.

T. L. Warrington, Lexington, Dawson County, Nebr.:

In the Platte Valley, sheet water can be obtained in inexhaustible quantities at from 8 to 40 feet from surface. On the table-land bordering on the Platte Valley, good water can be had from 80 to 300 feet.

H. W. Worthington, Richfield, Morton County, Kans.:

The underflow of the north fork of the Cimarron and Santa Arroya furnishes a ready supply of water for stock when the rivers themselves are dry.

S. J. Wilkinson, Logan County, Kans.:

The Hackberry is a small stream running through this part of the country from west to east and dry most of the year, but a great supply of water is found beneath the surface at a depth of from 3 to 10 feet in the valley. The flow is much stronger near the bed of the stream. In the extreme dry weather of 1889, I dug a well for stock-water within 20 feet of the creek bed. The mouth of the well is about 3 feet above the creek bed. We struck water at about 5 feet, thus showing the water line to be but 2 feet below the bed at that point. Water was struck in sand and gravel into which we sunk a box 2½ feet, as far as we could go on account of the immense inflow of water. As to the depth of the underflow water there is nothing known, because, though we have dug wells in the valley, our people have always felt satisfied after obtaining 2 or 3 feet of water, and that is as far as the underflow has been penetrated to my knowledge.

E. C. Holmes, Russell Springs, Logan County, Kans.:

There is a bountiful supply of underflow water in all streams which run across the south part of this county; also in the valley of the Smoky River through the center of the county.

J. C. Starr, Scott City, Scott County, Kans.:

We have along the Whitewoman Creek an inexhaustible supply of running water. A 12-inch bored well about 40 feet deep on the Hughes Cattle Company ranch, located on the bank of Whitewoman Creek, supplied water for nearly 1,000 head of cattle in 1887. The well never failed nor was the water mark lowered during the dry season of the year. This is on section 12, township 19, range 33. I have a dug well on the southeast quarter of same section, 17 feet to water, well 23 feet deep, which probably furnished more water to the traveling and freighting people in 1886 and 1887 than any well along the public road and it never failed, besides supplying plenty of water for my stock. Water in the center of the Whitewoman basin is found at 12 and 15 feet. Moving back toward the highland, the depth to water gradually increases until a depth of 40 to 50 feet is reached.

### Judge E. J. Fields, Leoti, Wichita County, Kans.:

We have the Beaver, White River, and two Sand Creeks in this county. There are large pools of water from 8 to 12 feet deep along the White River, which are evidently sheet water. Some parties from Kansas City began a ditch or channel to test the capacity of this under water by a ditch three-quarters of a mile long. On one occasion I measured the stream about 300 yards above the place of beginning, and it was running at the rate of about 4 miles an hour, was 6 inches deep and 30 inches wide. The next day they had gone 150 yards further, and it had gained so that it was 9 inches deep and 30 inches wide, and the deepest place in the ditch was not over 5 feet. It is my opinion that by going to the proper depth water can be got to irrigate a large amount of land by the use of reservoirs, and the same thing can be done in the Sand Creeks. The Beaver is a running stream, but it sinks in the sand in some places and rises again in others. It has many pools of water from 6 to 15 feet deep. The water runs in some places on riffles 6 inches deep and 15 feet wide, and it has been estimated that there is twenty times as much water flowing through the sand immediately underneath. There is a spring in the northwestern portion of Greeley County, near the State line, called Barrel Spring, because an old settler sunk a barrel there, and I am told that in 1889, when the land was taken up and the people had no wells, they came from a radius of 10 miles around with wagons filled with barrels, and one man who lived near says that he has seen them from dawn until after night, two men at a time, dipping with buckets and pouring into barrels, and they never could lower the water level lower than 18 inches. We have numerous wells through the county that have been tested through all the power they could get by means of pump for a day at a time without lowering the water an inch.

### Judge James Glynn, Holyoke, Colo.:

So far as I can learn sheet water underlies the whole country, ranging in depth from 100 to 150 feet, with a few deeper places in the table-lands north of them. I have never heard of any boring made without striking water. I have learned of several water holes from 20 to 50 feet in diameter in which water neither increases or diminishes during the year. They are principally along a dry creek called "The Frenchman." I am well satisfied that if the underground flow of water in the Frenchman was brought to the surface by the fountain system, which could be done in a little less than a half mile, and the water stored, this entire county and the counties south of us could be irrigated successfully.

### Hudson Harlan, Wa Keeney, Trego County, Kans.:

In the Smoky Valley, which is similar to the Arkansas, there seems to be an unlimited flow in the sand, gravel, and eroded material lying above the shale from 3 to 20 feet in thickness and from 100 feet to one-half mile in width. The Saline, in the north part of the county, is similar, but not so great in volume. Big Creek would also furnish a small canal.

### James Belton, North Platte, Nebr.:

I have been in this city twenty-one years, and have put down a good many wells. Our elevation is 2,780 feet. The slope here is about 10 feet to the mile. At about 4 feet from the surface in the valley of the Platte a crust is formed, beneath which comes the water and sand which prevail for the next 15 feet. Then hardpan is struck and strata of other material; but at a depth of from 80 to 195 feet a second water-bearing stratum is found, from which the water invariably rises to 3 feet from the surface, giving an inexhaustible supply of water. To the north of the river it is sandy, but water can be had anywhere from 50 to 150 feet, according to the character of the surface. To the south of the river the land is more of a clay soil. Water can be had anywhere from 75 to 225 feet. Every 7 or 8 miles north of the river springs come out of the valley large enough to run mills, but south of the river there are very few. There is no question but that this country is underlaid with any quantity of water, and if brought to the surface millions of acres might be reclaimed, of as rich land as there is in the world.

Theo. T. Schroeder, of Kit Carson, Colo., speaking of an experimental well by the Government at what is known as Cheynne Wells, Colo., says:

At 260 feet a vein of water was struck, but the object being to get artesian water the vein was cased off by 10-inch casing and boring continued to a depth of 1,740 feet. No artesian water being secured, the Government abandoned the well, and the Union Pacific Railroad Company opened up the vein of water, which was cased off at 260 feet, and has powerful machinery with which to raise the water therefrom. For some months I had charge of this machinery and was able to pump from 2,800 to 2,900 gallons per hour, with a Knowles deep-well pump, requiring 70 to 80 pounds of steam pressure to pump. Considering that the well only consists of a 6-inch casing in which the plunger works, it certainly takes a strong vein of water to keep up the discharge of 2,900 gallons per hour.

H. R. Dellinger, Hyannis, Grant County, Nebr.:

James Forbes, our county treasurer, drove a sand point down 23 feet on section 20, township 22, range 39, and attached a double cylinder pump and windmill, which affords abundant water for 800 head of cattle.

A. J. Mowry, Lucerne, Decatur County, Kans.:

In township 8, south, range 27 west, near the town of Guy, is a strong artesian spring that throws a strong volume of water and fine sand. I am located in the Bow Creek Valley, at about an elevation of 115 feet above what we call sheet water, found in coarse sand. The water is inexhaustible when reached. A 6-inch bored well will supply 3-inch cylinder in force pump and, with windmills, as long as the wind blows and mill runs, there is no lack of water.

John Maxwell, Menlo, Thomas County, Kans.:

One of my neighbors, Mr. Thomas Huey, went into his pasture in the Solomon bottom and, with plow and scraper, dug out an excavation down to water. The Solomon River does not run in this part of the county. His place is about 80 feet below the average level of the country.

C. S. Wilmuth, Water Valley, Kiowa County, Colo.:

We have sheet water in our wells, and we have a stream that flows under the sand 4 feet of water, 100 yards wide.

The Southwestern Sugar Company, of Meade, have a well 6 by 8 feet and 103 feet deep. It cost $250. Robert McHatton, of Meade, states that no log of the strata was kept. The water, when found, rose to nearly even with the level of the ground. The water brings up a little coarse white sand.

Mr. E. D. Smith, of Meade, says:

First a well was bored at the mill, producing a flow, but not enough for the purposes of a sugar mill, and then one was sunk with pick and shovel, 6 by 8 feet, on ground a little higher than the first; at a depth of about 100 feet the whole bottom burst up and the workmen barely escaped with their lives. The water rose to within 18 inches of the top, where it remains.

A well owned by John W. Hudson, in the extreme northern part of Meade County, on a section adjoining Gray County, at an altitude of 2,630 feet, was dug and bored 113½ feet. The first water was found at 73 feet and rose 4 feet. At 113½ feet a flow of water was found in white quartz gravel, which came up freely through the pipe, carrying up quantities of the gravel. The water rose to a height of 81½ feet, or within 32 feet of the top of the ground, where it remains. A log of this well was furnished by Capt. John A. Shaw, of Montezuma, Gray County. He also gives the following particulars relating to a well 9 miles west of the foregoing:

James Holcomb's well, on the northwest quarter of section 4, township 30, range 29, in Crooked Creek Valley, was begun in 1887—bore 2 inches in diameter; struck first water at 20 feet; second water, 110 feet in coarse sand. The upward flow of sand was so strong that it fastened the drill, which was broken and left in the well. The water rose to within a few feet of the surface, and remains so at the present time, with the drill embedded in the bottom of the well.

The foregoing extracts are simply illustrative of the general opinion of the inhabitants of the division. The opinion is based, of course, upon the fact that most of the wells obtain their water from the grit, which is found at some depth under the surface, as a rule. There are exceptions, however. A very common phenomenon is the rise of water in wells, upon various portions of the plains, above the point where found. Sometimes the rise is rapid, even violent, and a flowing well is, for a few minutes or a few hours, expected by the well-borer; but the water supply rises a foot or two, 40, 50, perhaps 100 or 200 feet and stands at what proves, upon careful examination, to be about the general level of the waters. A very few extracts from correspondence are given, following. Such instances could be multiplied by thousands in this division:

J. E. Carpenter, Morton, Morton County, Kans., describes a well 69 feet deep, in which the water rose 4 feet and says:

At the bottom of the well there seems to be a regular flow of water, the same as the undercurrent of all these streams.

Henry Stahl, Norton, Norton County, Kans., describes a 12-inch bored well 113 feet deep, in which the water rose 6 feet, and says:

The well-borers say that in all deep wells the water rises some. Before we put down the tubing, we put down some paper and it circled around on the current.

Robert Chadwick, Lewellen, Dawson County, Nebr.:

Watered 230 head of stock from a 2-inch bore well, and believe I could have easily watered twice the number. Well 106 feet deep, and containing 75 feet of water.

W. F. Brown, Craven, Pratt County, Kans., describes a well 70 feet deep in which the water rose 35 feet, and states that the water rises in the neighboring wells in the same way.

S. S. Mathes, Little River, Reno County, Kans., says:

I have bored many wells in Rice, Reno, Ellsworth, and McPherson counties since 1875, and in many places the water rises above the place of tapping the strata.

J. K. Sayre, Ensign, Gray County, Kans.:

Water rises in wells from 6 to 8 feet all over the county.

E. H. Grosclund, Ulysses, Grant County, Kans., describes a well in which the water rose 60 feet, and says:

There are many such wells all over the county.

J. C. Kilborn, Morton, Morton County, Kans., describes a well in which water rose 30 feet, and says:

There are other wells in my locality same as my own.

J. M. Helfrick, Pence, Scott County, Kans., describes a well as follows:

It is a tubular well, 2-inch gas-pipe driven to the bottom. At 175 feet the water rose in the pipe 80 feet with force enough to fill 10 feet of sand in the pipe.

F. P. Hill, Stockton, Rooks County, Kans., describes a well 184 feet deep in which water rose to within 50 feet of the surface, and says that the wells in his vicinity show about the same rise.

G. Schwabb, La Crosse, Rush County, Kans., describes a well 267 feet deep, in which water rose 100 feet, and says:

Wells of this description can be obtained anywhere at a depth of 130 to 267 feet. Water rises in them from 80 to 160 feet. There are a great many wells of this sort in all parts of the county.

D. A. Smith, Delhi, Russell County, Kans., describes a well 240 feet deep, in which water rose 24 feet, and says:

> There are several similar wells in this vicinity, ranging in depth from 140 to 240 feet. All are located on high ground.

W. G. Arnolds, Lamar, Chase County, Nebr.:

> This well is 136 feet deep. Struck water at 100 feet. Second sheet at 120 feet. This sheet was 6 feet through and the water rose 3 feet above first sheet, and the last sheet struck rose 9 feet above the first sheet.

The partial rise of the water in such wells is popularly taken as an indication that deeper boring would produce a flowing artesian well, but it has no such significance. The causes of such phenomena are fully discussed further on.

It seems quite clearly established that the shales and other formations which underlie this region were so eroded as to present a very uneven surface when the formation known as the Tertiary grit or "mortar beds" was deposited. Of this formation Prof. Robert Hay, F. G. S. A., chief geologist of the "Artesian Wells Investigation," says:*

> The term grit is descriptive of this formation everywhere, yet it is of varying constitution. In places it incloses a fine powder, but the powder is largely siliceous, is useful as polishing powder, and appears to be volcanic in its origin—wind-blown volcanic glass from the Tertiary centers of eruption in the west. Elsewhere the grit is an aggregation of sand and lime, which we call its mortar-like form. Again, the lime exceeds the sand in quantity, and it is sufficiently fine to be used for inside plastering. Then we have the mortar form, inclosing abundant pebble, quartz, feldspar, diorite, greenstone (hornblende), and more rarely, granite, with other igneous rocks. Then the limy matrix almost disappears, and we have a heavy conglomerate of water-worn pebbles of the rocks above mentioned, with jasper, quartzite, and agate, from the size of a nut to that of a large apple. Sometimes also there is a bone or a piece of completely silicified wood. The mortar-like form often hardens into a building-stone, and its softer beds contain hard, tough nodules like indurated, not silicified, chalk. The conglomerate form changes at times into beds of a fair quality of sandstone. In some places it shows as a hardened bed of gravel, with well-marked cross bedding. The mortar-like form is often a fossil bed, yielding bones of mastodon, *Aphelops*, and turtle. There are in many places root-like concretions penetrating the softer forms of the grit, and where these softer forms are of considerable thickness—they attain in places a depth of 15 to 20 feet—they are characterized by harder ledges at intervals of from 2 to 3 feet, which give very bold forms in weathering. The conglomerate is also manifested in abrupt breaks and rocky ledges.
>
> In the Arkansas Valley the conglomerate of the grit is mainly composed of pebbles of dark red feldspar. This is so marked a feature that its exposures, covered with the loose pebbles, can be recognized at long distance by their ruddy glow in the sun. In the valley of the Cimarron and in counties farther east the conglomerate is more often composed of quartz pebbles and pale feldspar, giving a whitish or grayish tint to the exposures. In several well-marked instances I found the mortar form and the conglomerate together, indicating that they are not, as I had at first supposed, local variations of synchronous deposits. I found the mortar form below the conglomerate, the former having in those places its usual scant supply of pebbles. Rocky Point, a bold ledge of conglomerate, 5 miles west of Dodge City, gave a juxtaposition of the two forms, the mortar form showing only on the eastern slope of the point and disappearing under the conglomerate. Elsewhere I found a mortar form embedding not only the pebbles of igneous rock, but also pebbles, both water-worn and angular, of the Cretaceous rocks of the region, these fragments being more or less silicified. A small patch of white sandstone, of which there were several near, in Harper County (sec. 5, T. 32, R. 5 W.), had similar relation to the underlying red rock (Jura-Trias). The red rock, a nodular clay, shades upward into the sandstone, the immediate part being a conglomerate of quartz pebbles in a pasty matrix of the red-rock material. The sandstone itself has some pebbles of smaller size, and in the conglomerate the larger pebbles are below, and the least amount of coloring matter—the pasty matrix—above. At another "Rocky Point" on the Cimarron, in Morton County, the grit lies on the Dakota sandstones, and great erosions of previous epochs are well illustrated by the difference of the formations on which the grit rests.
>
> This description of the Tertiary grit is that of a formation by no means confined to Kansas. While it is found in at least 20,000 square miles of that State, it is also con-

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* Senate Ex. Doc. No. 222, Fifty-first Congress, first session, p. 42.

spicuous in an equal area of eastern Colorado, a larger area of western Nebraska, and in similar areas of New Mexico and Texas. Its character for holding water is continuous through all that region. On the level prairie it is covered up with what we have called Tertiary marl, a loose-like deposit, not altogether impervious to water, but so much so in most of its area as to hold down the accumulated waters in the grit. The marl varies from 20 or 30 to 200 feet in thickness, and the grit is from 20 to 100. Through all this region the high prairie wells are sunk through the marl and find abundance of water in the grit. Neither steam or wind pump reduce their supply.

## SOME PECULIARITIES.

It is this formation which holds what is known by the inhabitants of the plains region as "sheet water." After being deposited, however, it was undoubtedly eroded to a considerable extent, being largely removed from the higher peaks and ridges of the underlying formations, and the sand and gravel, which were its chief components, deposited in the deep basins, valleys, and cañons which dotted and seamed the former surface. Thus, while the grit lies, in general, in beds varying from 10 to 100 feet in thickness, as described by Prof. Hay, it is worn to a "feather edge" in places, and the deposit of broken-down grit is, in other places, upward of 300 feet in depth, while knobs, peaks, and ridges of the impervious subformations were left bare and protruding, and some of these still show, in places, through the immense marly deposits afterward spread over the whole.

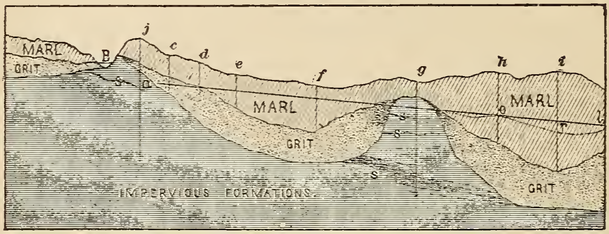


FIG. 6.—Various characteristics of wells.

The accompanying diagrammatic sketch (Fig. 6) will illustrate and explain most of the phenomena observed in sinking wells upon the plains. In many places, especially in northwestern Kansas, exposed ledges of shale may be found, generally on the south, or abrupt side, of a stream. At such places will almost always be found a stream or pool or succession of pools of water with shaly bottom. Wells put down to the southward and in the near vicinity of such shale banks uniformly penetrate only dry shale, as shown at *j*, though a very slight "seep" of water may be found, as at *s*. A well, as shown at *c*, will penetrate dry sand and gravel for a few feet, then reach that which contains water in plenty, the water line being indicated by the line *a b*. A shale bottom may be reached, as shown in the diagram, or the digger may simply stop in the grit as indicated in well *d*. The latter is an example of the well in which water is found immediately upon striking the grit, but in which the water does not rise. A well, as at *e*, may penetrate about the same thickness of marl, as at *d*, and in the near neighborhood, yet the water will rise in the well several feet. At *f* the well-borer will go much deeper than at either of the preceding two, but the water will rise much more extensively in the well and stand permanently nearer the surface, for obvious reasons, it being remembered that the dense deposit of marl is practically impervious to water. At *g* is shown what often occurs. The well-borer strikes a peak or ridge of shale at some distance below the surface, without having obtained water. In such a well the "sheet water" is not found by the well-maker. He finds an occasional "seep" of water, as at *s s*, and may consider himself fortunate if he finally secures, at an unusual depth. a strong enough "seep," through numerous small fissures, to furnish him a limited supply of water, which may, by the practice of economy, answer his purposes.

Sometimes, as at *h*, the borer passes through a thin vein of water-bearing grit, as at *o*, which does not furnish a sufficient flow of water. Upon boring farther an abundant supply is obtained, which rises to the level of the other stratum, thus showing a common source. At *i* the surface of the ground may be higher, accounting to a degree for the lenticular under-line. The above-mentioned thin water vein will be penetrated, as at *r*, and when the "sheet water" is reached there is a strong rise of water which maintains its level some feet above the vein first penetrated. The deep well at Santa Fe, Haskell County, Kans., is an illustration of this sort of condition.

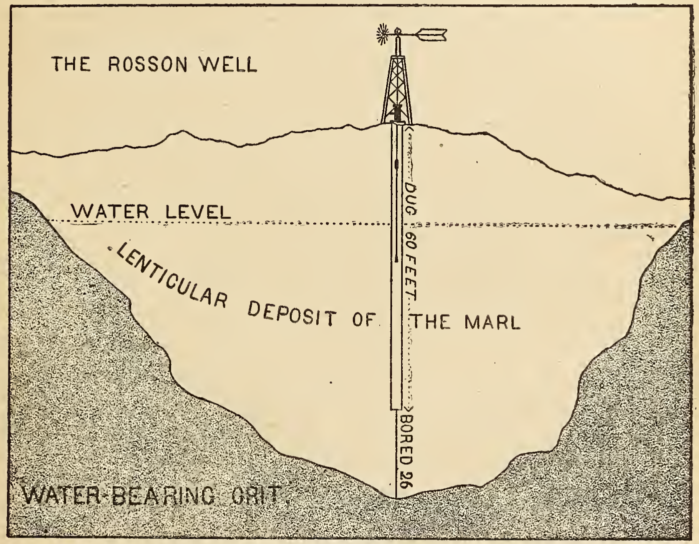


FIG. 7.—A southwest Kansas well.

Another well of this type (see Fig. 7) is that of J. J. Rosson, in the valley of the north fork of the Cimarron River, in Grant County, Kans. It is the well referred to by E. H. Grosclund, in the extracts from correspondence foregoing. The well is dug 60 feet deep in the top of a mound embracing less than a quarter section of land. Obtaining no water by digging to the depth mentioned, a 2-inch hole was bored in the bottom to a depth of 20 feet more, when the water gushed up with such force that it soon stood within 20 feet of the well's mouth. The well is used to water some fifty head of stock and to irrigate a garden. An 8-foot windmill can not affect the supply. That this well simply chanced upon a lenticular lump of densely packed marl is proven by the fact that wells in the immediate vicinity strike the sheet water at a depth of a few feet and at the same level as the water in this well.

### ITS DEPTH.

Reliable facts concerning the extreme depth or thickness of the strata which contain the sheet water are very meager and hard to obtain. For the reasons already stated, very few wells penetrate to the bottom of the water-bearing stratum in which an abundance of water is found. Prof. Hay's estimate, as already quoted, is that the grit varies in thickness from 20 to 100 feet. There are considerable areas in which the stratum utilized for obtaining water, averages but about 2 feet in thickness. What there may be farther down is as yet undeveloped. On the other hand, in the former cañons, above which now flow some of the principal streams, there is a great depth of water. An experimental boring at Garden City, Kans., passed through 320 feet of alternating layers of water-soaked sand and gravel. In the southwest corner of Morton County, Kans., a casing of galvanized sheet iron 40 feet in length, all firmly riveted together, was put down in a well 114 feet deep, and as soon as released from the ropes by which it was lowered it sunk down its whole length and wholly disappeared in the unknown depths of a bed of sand and water.

There have been quite a number of deep borings made throughout the division, but it is next to impossible to obtain anything like a reliable log of one in a score. In most cases no accurate record was kept of the strata penetrated, and where such a record was made it was, as a general thing, soon afterward lost or destroyed. For these reasons no satisfactory estimate of the average depth of the sheet water, so generally found, can be made at this time. I am satisfied, however, from the facts gathered, that it may be safely said to average not less than 15 feet in depth under the whole area of this division. This takes into account the fact that there are numerous peaks and ridges of shale which penetrate the sheet water from below, and that in places the water above the non-water-bearing strata is quite shallow over considerable areas. It is to be understood also that by the term "sheet water" is meant the water so generally found at an average level, whether in sand and gravel, in the more rigid form of the "mortar beds," or the still harder water-bearing formations which, in some localities, take the place of the more generally distributed grit.

### ITS QUANTITY.

Careful tests show that each pound of what might be considered an average of the grit contains a little more than one-fourth pound of water. Hence each cubic foot of this saturated medium contains above one-third of a cubic foot of water. Considering the nature of the mortar beds and the water-bearing sandstones, this is probably a fair average of the amount contained in the strata which bear what is popularly known as the sheet water. Upon this basis there would be an average depth of at least 5 feet of water underlying the whole area of the plains. I am convinced that this estimate is well within bounds.

### HOW THE WATER GETS IN.

While it is true that there is, as a general fact, a vast mass of compact, apparently dry, and practically impermeable marl overlying the

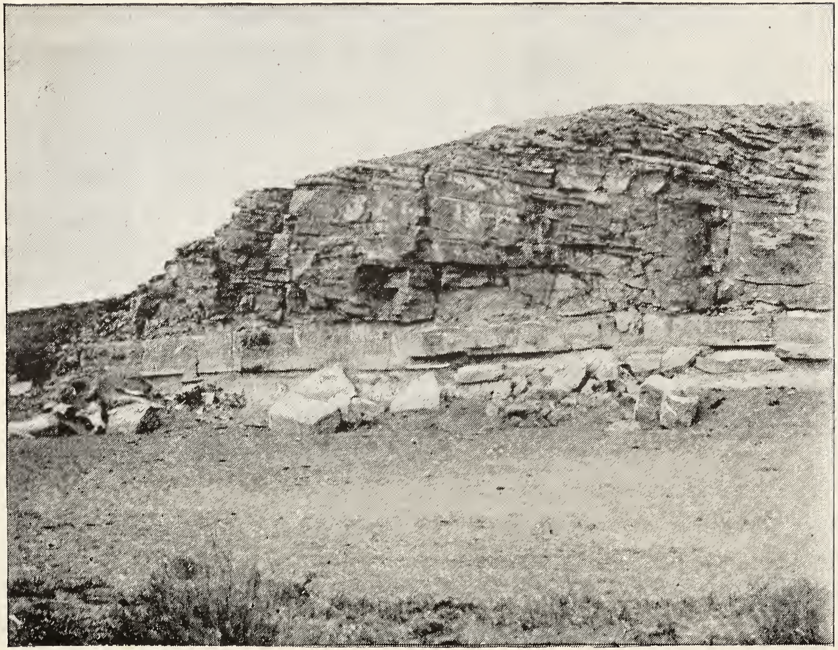


Fig. 8. View of Formation on Bear Creek, Colorado.

[From a photograph.]

plains area, there is no lack of openings through which surface waters may reach the permeable strata below. Every great stream is a gash through the marl, which acts as an equalizer, draining the underwaters, to a certain extent, at low stages, and adding thereto at times of flood. Every "draw" affords more or less means of reaching the underlying grit, and over the surface of any broad stretch of plain may be found myriads of holes made by coyotes, badgers, prairie dogs, and lesser animals, through which, in the aggregate, much water finds its way down through the marl. The occasional areas of sand-hill country afford, of course, no resistance to the direct percolation of all rainfall in excess of what is held in suspension in the sand itself. There are a number of so-called "creeks," some of them of considerable length, having broad sandy beds and numerous tributaries, draining large areas of country, and through which great floods of water pour at times, yet which have no outlet into any other stream or visible body of water. Among the most notable of these are Whitewoman Creek and Bear Creek. The former rises in Eastern Colorado, in Kiowa County, traverses Greeley and Wichita counties, in Kansas, and ends in a broad basin in the center of Scott County, through the bottom of which the water, which sometimes comes down in great quantities, quickly escapes to the sheet water below. This creek drains an area of some 1,500 square miles. That is, it is the outlet for such of the surface waters as escape above the surface of the ground. Bear Creek rises in Baca County, in southeastern Colorado, traverses portions of Stanton, Hamilton, and Kearny counties, in Kansas, and is lost in a line of sand hills south of the Arkansas River. With its tributaries it affords drainage for a scope of country over 100 miles long and averaging probably 40 miles wide.

This creek affords, perhaps, the most visible means of losing water throughout its course, instead of retaining it, of any of the numerous streams of its class. From first to last it cuts through ledges of a hard stone containing so much iron that the exposed and weathered surfaces are of a dark red color.

This stone lies in strata which uniformly dip away from the bed of the stream toward the southeast, and which rest upon a porous sandstone, in and from which the artesian wells of Morton and Hamilton counties, Kans., secure their artesian flow. The accompanying view (Figure 8) from a photograph taken on Bear Creek, near what is known as "Five Mile Water Holes," in Baca County, Colo., illustrates this peculiarity. The upper formation, the strata of which dip toward the southeast, is of the hard red stone above mentioned. The underlying and apparently level formation is the whitish sandstone, which freely permits the passage of water. The sandstone is rarely visible as in this instance, but this outcrop shows how readily the water of this stream constantly escapes from its channel into the porous sandstone below, so that only in times of copious local rains does any water flow visibly through the whole course of the stream down into its basin in the sand hills. There are many other and smaller streams similar to the two cited, having no visible outlet.

The "Big Sandy," which rises near the crest of the "Great Divide," in Colorado, and runs southeasterly, opening into the Arkansas, affords a means of escape of surface waters into the underflow by somewhat different means. Its channel, cutting across the plains, instead of following down the slope, affords a sort of lead-trough arrangement, over the edge of which, through gaps and low places in the shale which form its eastern lip, its waters find their way in underground streams, broad or narrow, between ridges of shale, down underneath the Kansas prairies.

Among the considerable sandy areas which absorb surface waters may be mentioned the strip of sand hills 50 miles long and averaging 10 miles in width south of the Arkansas River, stretching from the one hundred and second meridian eastward; the Arickaree Flats, in northeastern Colorado; the sandy country north of the Republican River, in southwest Nebraska; the sandy areas at the head of the Big Sandy, above referred to, and similar regions along the upper courses of the Canadian and its tributary, the Beaver, in "No Man's Land."

### HOW TO GET THE WATER OUT.

Aside from the utility of these subterranean water supplies for watering stock, supplying cities, railways, etc., for which they have proven so abundant that all forms of domestic use seem not to tax the supply in the least, the great interest in this division at the present time is how to recover and use such waters for irrigation. The means of such recovery may be roughly classified as: (1) By hoisting machinery, driven by steam, wind, or horse power; (2) by force of gravity, and (3) by artesian wells. Of the various forms, capacities, cost, utility and economy of pumps, hoisting apparatus, engines, windmills, etc., which are and may be used for the purpose of raising underwaters for use in irrigation, an interesting volume might be written, and one which would be of great value to those who now and will hereafter desire to employ such means. At the present stage of progress in the use of such means of irrigation I will not undertake a detailed report upon this feature. Many details as to the simplicity—or the contrary—of the machinery to be employed, the land to be irrigated, the height of lift, the contiguity of markets, the costs of fuel, etc., must necessarily enter into consideration in undertaking an exhaustive treatment of this branch of the subject. Suffice it to say that such means have begun to be employed quite largely and with some degree of success, which must be largely added to as experiments with the machinery and experience in the processes of irrigation are more extended.

The accompanying view (Fig. 9) is from a photograph of one of the most primitive and inexpensive of wind engines. It is made of rough lumber, at a total cost of $16, and supplies sufficient power to raise an abundant supply of water for 50 head of cattle from a depth of 45 feet; also to irrigate a small garden, run the family churn, etc., with an uncalculated increment to spare. The principles of its construction and operation are of the simplest character and are apparent at a glance. The fixity of the mill in its place is because of the fact that all winds of any account whatever, upon the Plains, blow either from the north or south, with such directness that the shifting of a mill to meet the breeze is not necessary, provided it is so arranged that its motion, whether in the one direction or the other, produces the desired result. Such a mill runs, of course, whenever the wind blows, whether its power is required or not, but modifications of this form of windmill have been invented in which the motion of the mill may be controlled and even suspended, at any time. The one shown is used upon a ranch in Morton County, Kans.

Within the past two or three years many small tracts of garden and truck patch have been placed under successful irrigation by utilizing the pumps and windmills erected for ordinary domestic purposes. These draw water from depths varying from 20 to 100 feet to success-

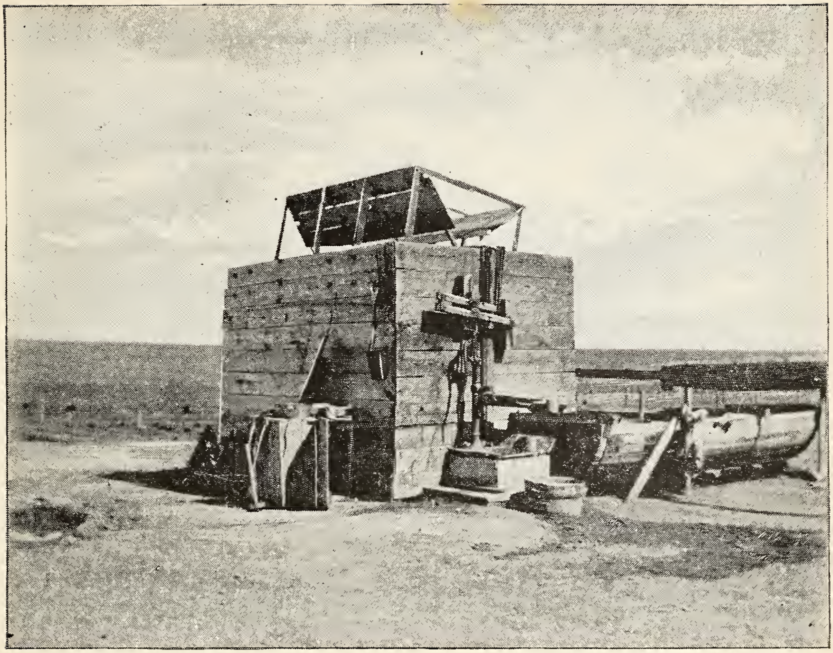


Fig. 9. A Pioneer Irrigator.
[From a photograph.]

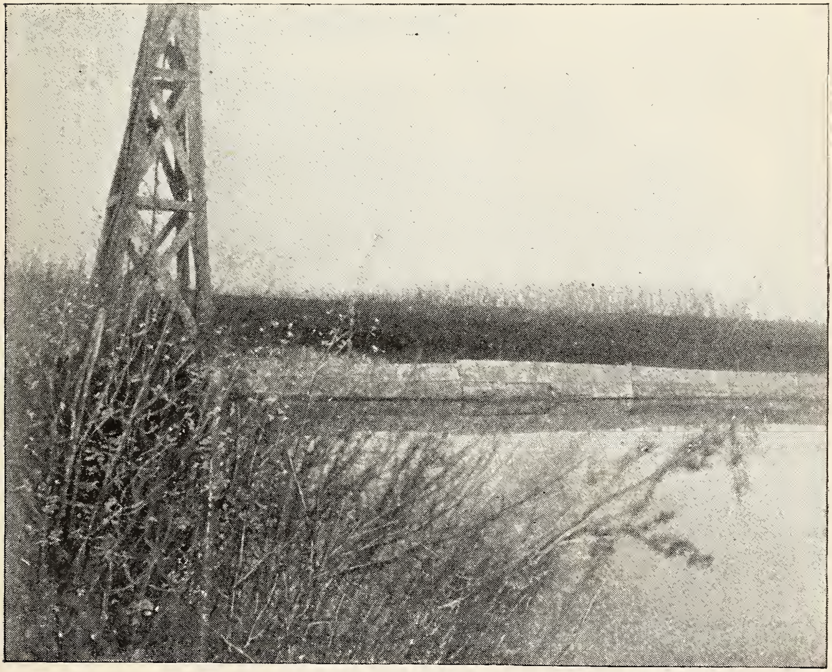


Fig. 10. Irrigation by Pumping—Mill and Reservoir.
[From a photograph.]

fully irrigate from half an acre to two or three acres. Of late there has been much inquiry for an improved form of pump which could be used to lift water 20 or 30 feet, in more considerable quantities, utilizing ordinary 8 or 12 foot windmills for power. Messrs. W. R. Grace, J. L. Deisem, John Simon, and E. J. Johnson, of Garden City, Kans., are each using a modification of the ordinary form of pump, called the Gause pump, which seems to give good satisfaction. The modification consists in simply enlarging the size of all the working parts of the pump, including especially the orifices of supply and discharge. It is used in connection with a small reservoir made by throwing up a border of earth inclosing an area, say 100 feet square, no lining or puddling being necessary. The accompanying photographic view (Fig. 10) shows part of the mill tower and reservoir used by Mr. Grace. He has a 10-foot mill, a pump of 5-inch cylinder and 8 inch stroke. His reservoir is 50 by 80 feet in size and 3 feet deep, the lining of rough boards shown in the view being for the protection of the banks against wave action simply. The water is hoisted 12 feet. With this "plant," costing $125 all told, he irrigated this year 4 acres, yielding a gross return of products to the value of $600, and avers he could have irrigated 10 acres if he had had the land. He uses his reservoir as a fish pond, also.

Among the many who are irrigating small tracts of ground from ordinary wells and pumps may be mentioned Mr. J. J. Rosson, of Grant County, Kans., and Hon. Benj. C. Rich, of Trego County, Kans.

The recovery of underwaters by gravity will eventually test many methods and probably employ several differing at least in detail. Up to the present time, that which is attracting attention, and to which experimentation has been confined is what is known upon the plains as the "fountain method." It consists of simply drifting from the surface of the ground into the water-bearing strata by means of an open cut or "fountain," having a less rate of inclination than has the surface of the ground, and of the water-bearing stratum penetrated. Reference is made to the accompanying diagrammatic section (Fig. 11) and explanations.

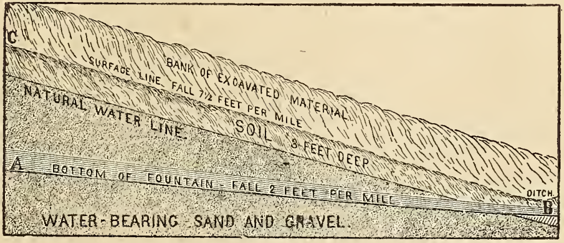

C
BANK OF EXCAVATED MATERIAL
SURFACE LINE. FALL 7½ FEET PER MILE
NATURAL WATER LINE.
SOIL
3 FEET DEEP
A
BOTTOM OF FOUNTAIN - FALL 2 FEET PER MILE
DITCH.
B
WATER-BEARING SAND AND GRAVEL.

FIG. 11.—How water is obtained.

## HOW THE WATER IS OBTAINED.

In the above drawing, which represents a longitudinal section of part of a "fountain," the slope of the land is exaggerated in order to make the method of obtaining water plainly apparent to the eye. Let the drawing represent a stretch of 2 miles of Arkansas River bottom, which has an eastward fall of 7½ feet per mile; hence, the surface at C is 15 feet higher than at B. The underlying bed of water-bearing sand and gravel, averaging 3 feet below the surface, is indicated. If the fountain be excavated so that the bottom will have an eastward fall of 2 feet per mile (indicated by the line A B) the bottom will be 11 feet below the surface at C and 8 feet below the water line, so that the water which rushes into the fountain from bottom and sides will readily flow out upon the surface of the ground at B.

This method of securing water from the underflow is under test in a number of places. The first to construct a fountain on this plan were Gilbert Brothers, of Dodge City, Kans., who made a cutting near the Arkansas River 9 miles west of Dodge City, on the south side. They first cut away the soil and top sand by means of plows and scrapers, making their fountain 50 feet wide. Then piles and sheet piling were driven along each side and the sand between was dredged out to a depth of several feet below the water level. Half a mile of fountain was made in this way, when it was decided that the sheet piling was an unnecessary expense and it was dispensed with, the fountain being extended as much farther without wall of any sort, the banks of sand and gravel being left without any support whatever, and these have successfully stood the test for the past two years. Figure 12 is from a photograph of the extreme upper portion, or head of this fountain. Figure 13 shows a view about midway of the length of the fountain, where a great sand bar was formed through the mistake of permitting water from the river to flow through at a time of high water. Figure 14 is a view from a point where the water is discharged from the fountain proper into the carrying canal. Both of these show the walls, formed of piles and sheet piling. This fountain has been in operation two years. Recent inquiry concerning it developed the following data:

Length of main canal served by this fountain, 35 miles; carrying capacity, about 100 cubic feet per second; total amount invested in system, about $50,000; amount spent on fountain portion, about $25,000; number of acres canal will irrigate in its present condition, about 15,000. When completed, which will be done next season, it will serve 25,000 acres.

It is explained that experimental features of this work were costly and that the same works could now, with the knowledge gained, be constructed at much less cost.

On the opposite side of the river from the irrigation works above described is the Eureka Canal system, having a main length of 96 miles, costing about $2,000,000, and covering a great amount of excellent land. The fountain to supply this system with "underflow" water is now in process of construction, the principal work being done by a centrifugal pump discharging an 8-inch stream of water, which carries with it from 25 to 50 per cent of sand. When a cutting 20 feet wide, 500 feet long, and 8 feet deep has been made its supplying capacity will be tested by pumping from it into the canal by means of powerful centrifugal pumps, the bottom of the fountain, as constructed, being lower than the bed of the canal. If the supply is found insufficient the fountain will be lengthened until it furnishes the required water, which will be pumped into the canal as needed.

Near Hartland, Kearney County, Kans., is located the second fountain constructed for the recovery of subwaters by gravity. It is at the head of the "Southwestern" system of canals belonging to the Southwestern Irrigating Company, with headquarters at Garden City. Figure 15 shows the present head of the fountain, which, like the others

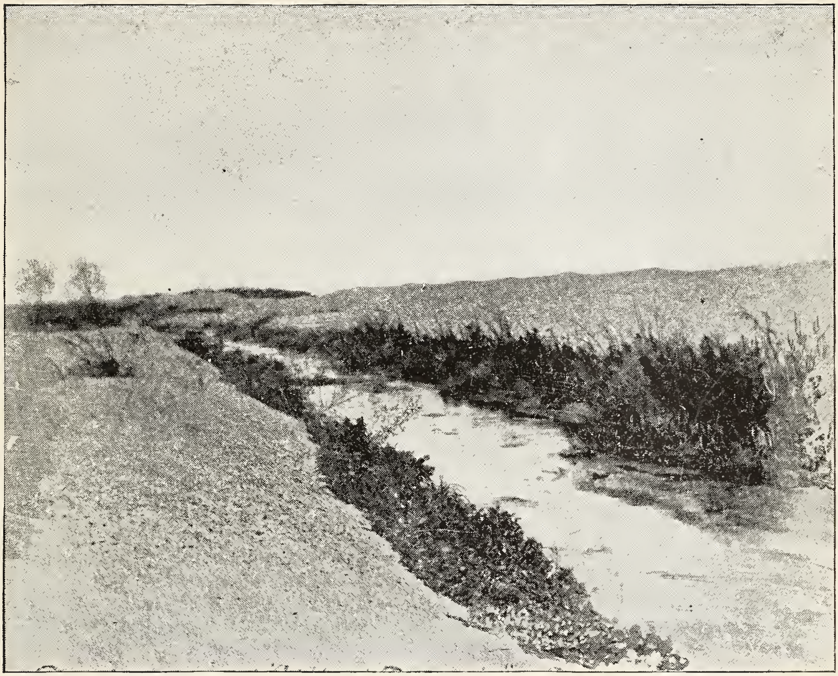


Fig. 12. Head of Gilbert "Fountain."
[From a photograph.]

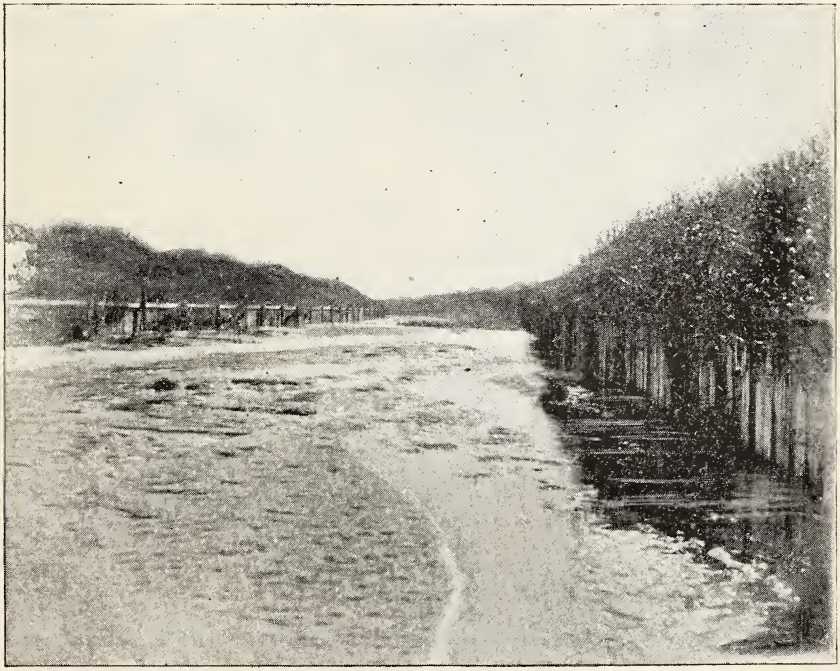


Fig. 13. View of Middle Course of Gilbert "Fountain."
[From a photograph.]

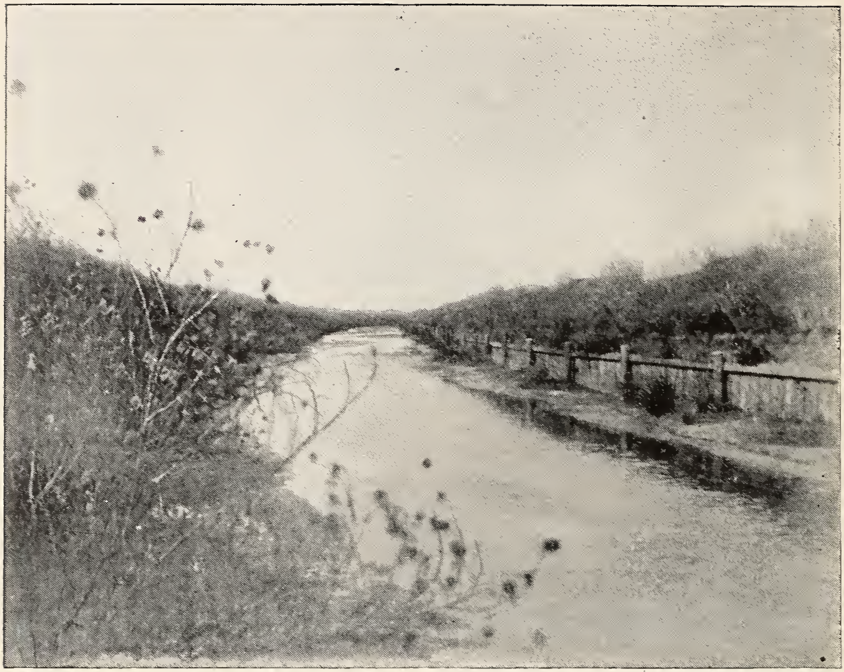


FIG. 14. MOUTH OF GILBERT "FOUNTAIN," NEAR DODGE CITY, KANSAS.
[From a photograph.]

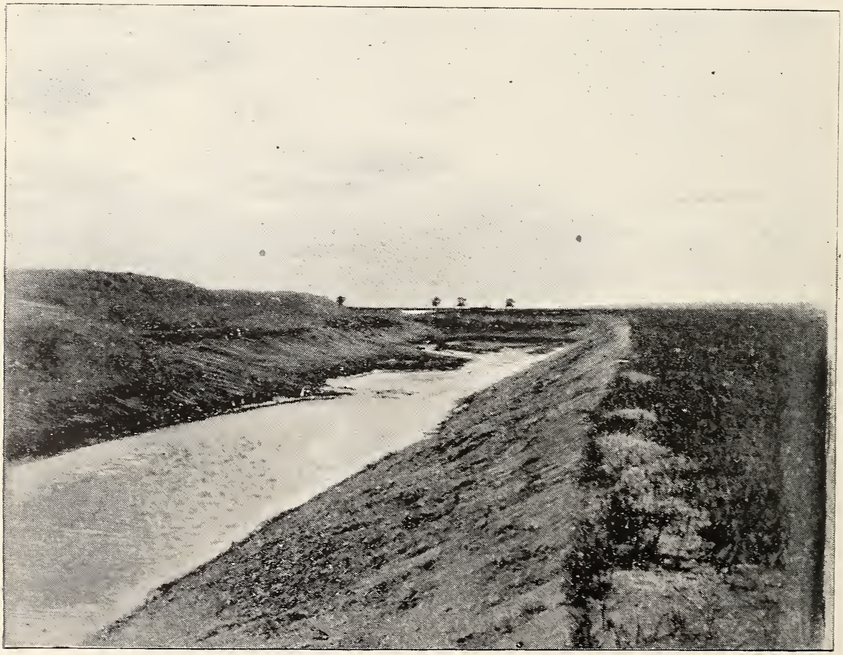


FIG. 15. HEAD OF "FOUNTAIN," SOUTHWESTERN CANALS, LOOKING WEST—ARKANSAS RIVER IN THE DISTANCE.
[From a photograph.]

mentioned, is constructed in the low land near the Arkansas River. The details as to its construction, the accompanying experiments, and the amount of water it furnishes at its present stage of progress are best told in the words of Mr. G. W. Potter, the engineer of the company. He says:

> When we commenced the work, about September 1, 1890, the river was dry. The river has a fall of 7 feet per mile, the underground ditch 3 feet per mile, and 18 feet wide on bottom, and approaches the river until it reaches within 100 feet of the north bank, when it continues parallel with it. Two thousand feet from place of beginning we struck water in a sand stratum. At 4,000 feet we made the first measurement, having a flow of 8,600 cubic inches per second, and the extent of drainage was also determined by digging eight wells at a right angle with the ditch, 50 feet apart. The elevation of the surface of water in the wells above the surface of water in the ditch is respectively as follows: No. 1, 50 feet north of ditch, .34 foot; No. 2, 100 feet north, .38 foot; No, 3, 150 feet north, 0.42 foot; No. 4, 200 feet north, 0.46 foot; No. 5, 250 feet north, 0.50 foot; No. 6, 300 feet north, 0.54 foot; No. 7, 350 feet north, 0.64 foot; No. 8, 400 feet north, 0.64 foot. It will be observed that the last two wells have the same elevation and 0.10 foot higher than the preceding one, due to a change in nature of the upper part of the water-bearing stratum, and shows the area drained by the ditch.
>
> At 6,000 feet we took another measurement of the flow, having 17,300 cubic inches per second; here we reached a coarse sand and gravel stratum.
>
> At 6,800 feet another line of wells was dug at a right angle with the ditch, showing the following elevations above the water in the ditch: Well No. 1, 50 feet north of the ditch, 1.21 feet; No. 2, 100 feet north of the ditch, 1.41 feet; No. 3, 200 feet north of the ditch, 1.60 feet; No. 4, 300 feet north of the ditch, 1.79 feet; No. 5, 400 feet north of the ditch, 1.96 feet; No. 6, 450 feet north of ditch, 2.02 feet. At this point the ditch is 3 feet deep in the water-bearing stratum and 5.25 feet below the bottom of the river; will drain an area 1,500 feet in width.
>
> The next measurement shows the supply of water obtained when we stopped work, 7,900 feet from the place of beginning. The supply thus obtained is 36,000 cubic inches per second.
>
> This stream has been constantly running for a year. At highest stage of water in the river, when it was 7 to 9 feet higher than the water in the ditch for a period of two months, and for 1,000 feet running within 100 feet of the river, the ditch increased in flow about one-third, which shows that the water is substantially obtained from the underflow, and by a continuation, which will be done soon, a substantial and almost unlimited flow can be obtained.

The following outline (Fig. 16) will serve to show the location of the fountain with respect to the Arkansas River, the main canal, and wells by which the drainage effect of the fountain was tested.

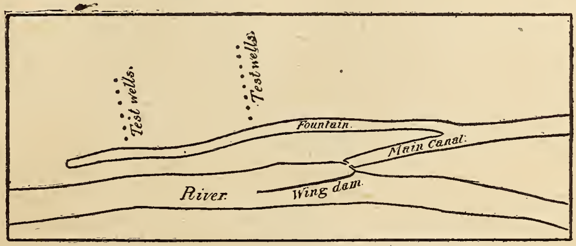


FIG. 16.—Relative positions of river and fountain.

Figure 17 is a view of the point of confluence of the underflow waters with the water from the river.

Beside the foundations described, similar works are now in operation or in an advanced stage of construction at Ogallala, Nebr; also on the South Fork of the Republican, above St. Francis, Kans., a part of the irrigation system of the South Fork Irrigation Company, under the management of Capt. A. L. Emerson. Near Limon, Colo., T. W. Lawrence & Co., of Denver, employ the same method to reënforce a water-storage system, and the "Amazon" Canal in Kearney, Finney, and Scott counties, Kans., which already represents an investment of $325,000, will proceed, the coming season, to expend large sums in securing the underflow. A feature of unusual interest in this connection is that the present head works of the canal connect with the Arkansas River immediately below a jutting, bluffy headland, which makes it necessary either to tunnel the point or to carry the canal around it by building a wall some hundreds of feet in length in the river. The latter plan has been adopted. Figure 19 is a view of the head of this canal, and the wing dam seen through the head gates shows the line of the proposed wall, which will extend around the obstructing headland, the proposed fountain being constructed in level bottom land beyond.

The "Western Canal," on the south side of the Arkansas River, opposite the "Amazon," is also preparing to utilize the underflow by the fountain method.

Many small enterprises of this sort will doubtless develop in the near future. One such has already taken shape. Figure 20 is a view of a reservoir constructed by Mr. Jas. W. McClain, in the valley of the South Fork of the Cimarron, in Morton County, Kans., and fed by the underflow of that stream by means of a shallow and easily made fountain. All the work on fountain, reservoir, and supply canal, sufficient to irrigate 10 acres of land with easily increased capacity, was done by himself with a team of "cow ponies," at spare times in the spring of the current year. I have word of the initiation of several individual enterprises of this sort.

Another means of recovering such subwaters is by the construction of a sunk dam, where there is a narrow valley with shallow underflow upon a bottom of shale, or other impervious substance. It should be obvious, without any labored demonstration, that such means can only be employed where the dam may rest upon an impervious bed not far below the surface and connect at its ends with walls or banks of the same kind, as otherwise the underflow could not be brought to the surface, but would simply pass under or around the dam. As there are but few localities where these conditions can be met, and they in small valleys having little under water, it follows that this means of recovery is of small importance in this region. There are several forms and modifications of the fountain method which might be tested with profit.

It is probably worthy of remark in this connection that the methods of water recovery described will be found of very great value indeed to other portions of the country, as well as the Great Plains. Several cities employ what is substantially the same plan in securing their water supply. Generally, in such cases, the open fountain is replaced by subcanal or pipe line piercing the under water. Denver, Colo., and Cheyenne, Wyo., have systems of this sort. Such works are necessarily expensive and could rarely be profitably employed for irrigation purposes.

### ITS SOURCES OF RENEWAL.

Some apprehension has been expressed by people in the lower portions of the valleys of the Arkansas and Platte that the use of the underflow for irrigation in the regions west of them may deplete their supply of water for domestic use. That the fear is groundless is apparent upon considering the vast amount of water now practically "in store" in the under strata, and it is unquestionably true that the widest possible utilization of the underflow, gradually brought about, will largely add to the subterranean waters instead of exhausting them.

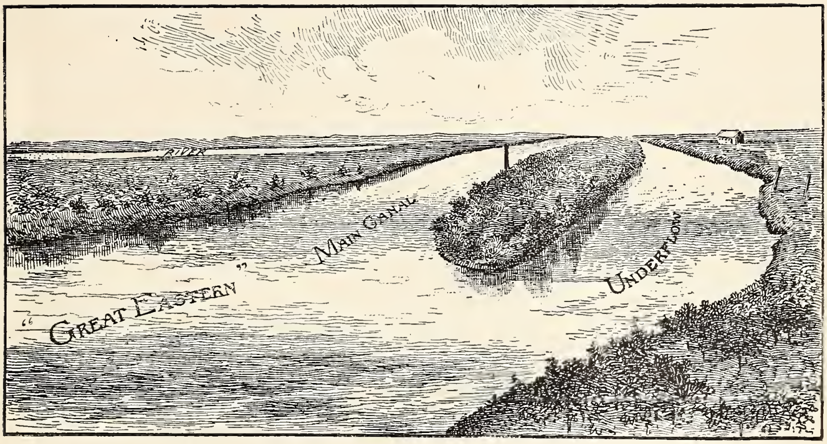


FIG. 17. CONFLUENCE OF "UNDERFLOW" AND RIVER WATERS, SOUTHWESTERN CANAL SYSTEM, KANSAS.

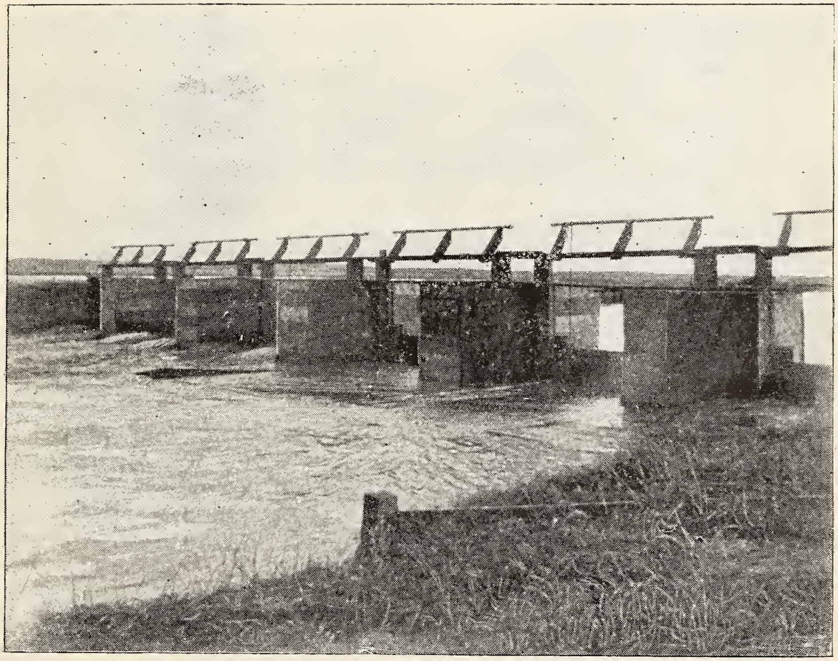


FIG. 18. HEADGATES, "SOUTHWESTERN" CANALS—ARKANSAS VALLEY, KANSAS.
[From a photograph.]

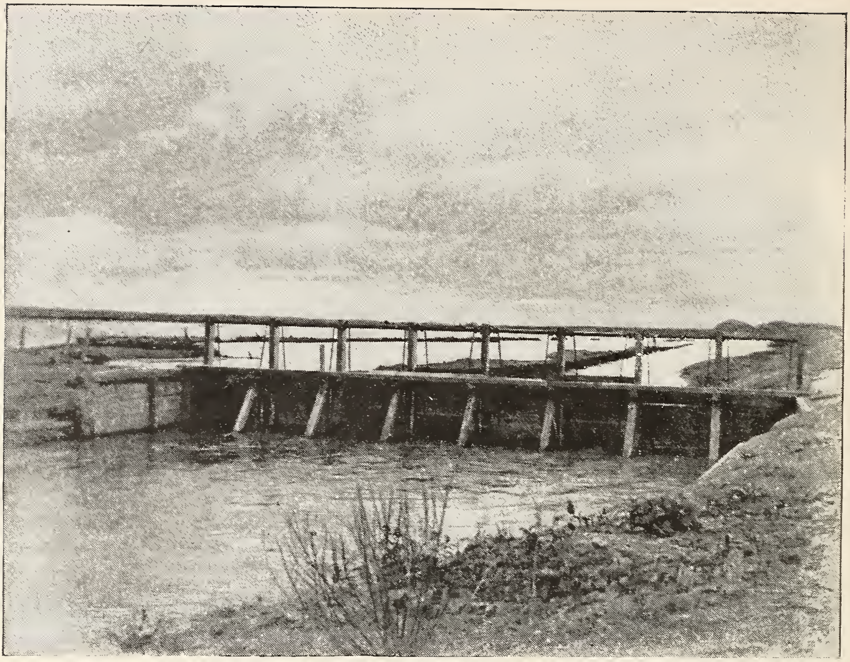


FIG. 19. HEAD OF "AMAZON" CANAL SYSTEM, ARKANSAS VALLEY.
[From a photograph.]

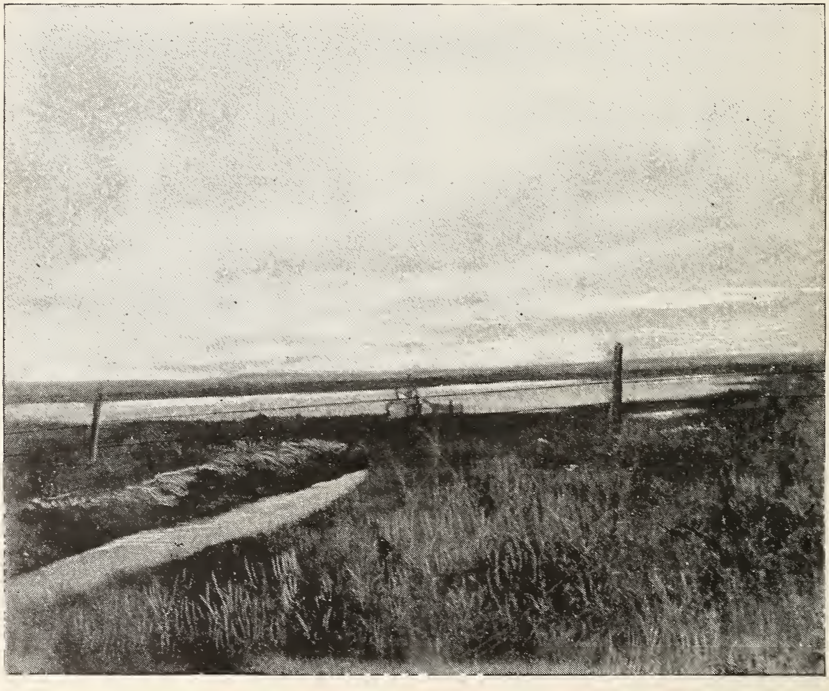


FIG. 20. McCLAIN'S RESERVOIR, CIMARRON VALLEY, SOUTHWEST KANSAS.

The employment of this source of supply will cause the utilization of much means of storage and the conservation of large quantities of waters now permitted to run to waste through the fall, winter, and spring, and at times of summer floods. If the annual saving and storage, whether in reservoirs or in cultivated fields, should amount to but 25 per cent of the present average annual waste, it would be ample not only to renew the supply but to increase it.

### ITS VALUE AS A FACTOR.

There are two features of the utilization of the under waters which render it a factor of transcendent importance in the problem of reclamation. One has just been referred to, namely, that it will cause the utilization of surface waters, the aggregate amount of which now going to waste is enormous, but which is unsalvable in detail. The addition of a small supply of under water to a small stream of surface water will render the latter profitable in hundreds of instances where the surface supply alone would not be worth saving. The second and great feature is the fact that by this means the same supply of water may practically be used again and again. In other words, a fountain* may produce water sufficient to irrigate 50,000 acres of land, which may be utilized within a distance of 50 miles, and the water, spread out over the ground and percolating through the soil back into the underflow, be ready for use upon the next 50-mile stretch below. It is not intended by this statement to ignore losses by evaporation, saturation, and diversion; these have their compensations which I have not now time to discuss. The fact is established that a large percentage of the water used for irrigation makes its way down into the water-bearing strata. Col. E. S. Nettleton caused measurements of the North Platte River to be made some time since at the cañon where it comes forth from the mountains, and, adding together the amounts of water actually taken from its volume by irrigating canals and the water found flowing in its channel 100 miles below, discovered an apparent increase of a trifle over 333 per cent. In other words, the water flowing out of the cañon was practically used three times in 100 miles.

The rapidity and extent to which saturation of the dry marl is already going on is surprising. Careful observations show that the water, in wells located along the courses of canals in the irrigated districts in southwest Kansas, has permanently risen from 2 to 50 feet in the past five years by reason of the saturation resulting from the flow of water in the canals. Thus the recovery of the subwater from the sandy beds where it flows uselessly, causes the added and increasing economy of storm waters, and these, gradually extending the growth of vegetation and adding to the saturation of the ground, both increase precipitation and add to the volume, stability, and availability of the phreatic stores. While it may be true, as so often asserted by authorities, that the records show no increase in the precipitation caught and measured by the rain gauge, it is a fact, apparent to every old resident of the plains, that there is in the irrigated areas a very large increase in the form of heavy dews, which add to the actual available supply of precipitated moisture. Thus these various forces, adding each to the potency of all the others, constitute an agency for the reclamation of the Great Plains, which, like a river of water, is accelerated in progress and increased in power as it widens and deepens on its way.

---

*The word "fountain" was adopted and is used by Mr. Gregory; the "investigation" decided on the term "sub-canals," and has used it every where else in the reports.

## RÉSUMÉ AND AMPLIFICATION.

In order to enhance the value of this report to some degree, as a suggestor of future work, the following is given:

1. The lands of the Plains country have been settled upon time and time again at great expense, but the effort to utilize them has proven futile except where irrigation could be secured.

2. Irrigation not only makes reclamation possible, but highly profitable, and will enable the plains to support a dense population.

3. By utilizing the underflow in conjunction with storage and other sources of water supply, general irrigation may be secured.

4. But the work of development and utilization must be on a broad and systematic plan, and the General Government can not possibly get rid of the necessity of regulating it.

5. To benefit the people who have earned the land, prompt action is necessary, and they have paid the Government so much money for land of this sort that comparatively a very small portion of it judiciously expended in practical experiments in securing the underflow and in aid of storage will do all that the General Government is desired to do in the way of appropriations to solve the irrigation problem for the Plains.

6. Irrigated lands ought to be owned and operated in small holdings.

7. The right to use water for irrigation must, in justice, become practically an appurtenance to the land, priority of appropriation being carefully protected, under proper limitations.

8. Very great power for use in manufacturing, etc., may be developed from the waters used in irrigation without detracting from their value for the last-named purpose.

9. By a general development of the water resources of the Plains region, it is possible that important modifications of the cost of transportation of the products and supplies of the region may be effected.

10. The retention of the waters, which now find their way from this portion of the country into the Mississippi River at times of flood, and their application to economic uses upon the plains would be a doubling of the beneficent effects of such retention; and should such waters eventually find their way by infiltration through the underlying beds of sand and gravel into that great stream, their steadiness of flow and their freedom from sediment would render them welcome and helpful instead of being, as now, productive of mischief.

11. By the proper utilization of their water supplies, the now bare and arid plains may be made to enter largely into the growth of timber and the production of fish.

12. The elements entering into the development and constant renewal of such water supplies are: The recovery of phreatic waters, storage, the growth of trees and other vegetation, irrigation, and the gradual saturation of the soil.

13. The evidence of the existence of great stores of subterranean waters in this region are (immediate), the vast aggregate discharge of springs, the disappearance of large streams of water, deep holes filled to a certain level with perennial water, the uniformity of an inexhaustible supply of "sheet water" in wells, the great depth and lateral extent of known deposits of water-soaked sand and gravel, the excess of rainfall over the visible outflow and probable evaporation (remote), large volumes of perennial water in the lower courses of large streams

when their upper courses in the plains are devoid of visible supply, distant subterranean streams, and the existence of great fresh water springs off the Gulf and Atlantic coasts.

14. The recovery of sub-waters may be accomplished by gravity through the "fountain method," by sunk dams, by sub-canals, and by driving or laying perforated or other permeable pipes and conduits; by pumping and hoisting by steam, wind and water power, the last eventually employing electricity as an important auxiliary; and subwaters may be recovered and used more than once.

15. The Great Plains region developed and utilized to the fullest extent may become, in an economic sense as well as geographically, the center and heart of the nation, such breadth and depth of fertile soil supplied with water for irrigation being a steadfast safeguard against famine; and it will be, or can be made, a region impenetrable by any foreign foe and capable of sustaining the entire nation throughout the duration of any probable foreign war.

16. While the cost of so reclaiming the semi-arid lands will be large, it will be insignificant compared with the resulting benefits and values, and these will be more than net gain because the irrigation of the Great Plains changes an enormous absorbent of wealth into a vast producer of the same.

17. Time is an element in the work of reclamation, not only because time is necessarily consumed in preparing for and building systems of irrigation works, but because trees must grow, vegetation must thicken and increase, and people must be educated in the school of experience to fit themselves to utilize and develop to the fullest extent the germinant possibilities of this hitherto greatly misunderstood and worse misrepresented region. Yet, if the work be but properly and expeditiously begun, judiciously regulated and systematically carried on, popular rights may be preserved, and, in the steady and healthful progress of development no one need find himself hedged about and ruined by misunderstood conditions, as in the past.

18. It is maintained by the people of the semi-arid region that there should be immediate provision by Congress for the preservation of reservoir sites and timber tracts; the arboration of large areas now bare, but which never can be of appreciable value for other use than for forest purposes; for the settlement in some general, just, and determinate manner of the legal questions which are constantly arising between the citizens of different States; and that it is also highly important that the development of all possible facts respecting the extent, sources of renewal, accessibility, and economic duty of phreatic waters should be pushed systematically and with all vigor.

## EXPLANATORY.

This report exhibits but a minor part of the work done prior to preparing it. The field under investigation being large, traversed by but few railways, which are parallel, wide apart, and have cross-connection only by means of long detours, both correspondence and travel consumed, comparatively, a great deal of time. The region being sparsely inhabited, the people new to the country, and but little definitely known of the subformations, the collection of exact information was tedious and difficult and results were often fragmentary. The time allowed by Congress for the investigation was brief, while the matters which it seemed ought to be treated of were numerous, important, and involved scanning by some means and to some extent more than 200,000 square miles of territory, and I must now confess that the collection of data was too long continued and not enough time reserved for preparing the accumulated material for publication. With so much "in sight," which it seemed ought to be done, it was hard to find a stopping place, consequently much valuable but incomplete material has been reluctantly laid aside at the last and several important features of the subject, which I had hoped to discuss fully, could not be taken up at all for lack of time.

I trust that abler investigators, hereafter, enjoying the advantages of sufficient time and means, may be enabled to disclose fully the facts concerning the vast irrigation resources which may be developed upon the Great Plains.

# A SPECIAL REPORT

OF

# WORK IN THE ARTESIAN AND UNDERFLOW INVESTIGATION, AND VIEWS OF CERTAIN CONDITIONS EXISTING IN SOUTH DAKOTA.

BY

FRED. F. B. COFFIN,
ENGINEER FOR SOUTH DAKOTA.

# ARTESIAN AND UNDERFLOW INVESTIGATION.

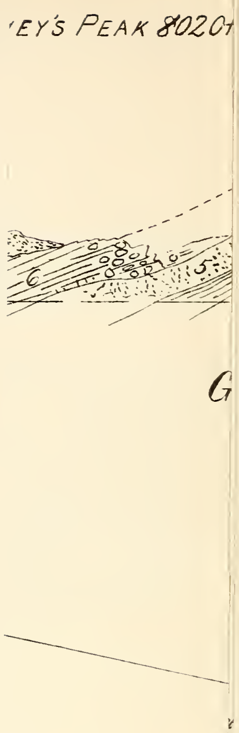
HURON, S. DAK., *December* 15, 1891.

SIR: I have the honor to transmit herewith my report of the part I took in the artesian wells investigation in South Dakota, and to give my views of certain conditions that exist in this State.

I have the honor to remain, yours, respectfully,

FRED. B. F. COFFIN,
*Engineer for South Dakota.*

HON. EDWIN WILLITS,
*Assistant Secretary of Agriculture.*



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PROFILE

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WATER BEA

Prepared by FRED. F. E

18

U. S. Department of Agriculture,

# PROFILE OF A LINE
FROM
# *Tracy, Minn. to Black Hills, So Da.*
## Showing ELEVATIONS, DEPTH OF WELLS
AND
## WATER BEARING STRATA

Prepared by FRED. F. B. COFFIN, Civil Engineer.

**1891.**

*No. 1.*

*Scale*
Horizontal, 1 Inch = 14 Miles.
Vertical, $\frac{1}{4}$ In. = 200 Ft.

*Geological Formation of Black Hills*

1. Granite.
2. Archaen Schists and Slates.
3. Cambrian (Potsdam).
4. Carboniferous.
5. Jura-triassic (Red Beds).
6. Jura-triassic (Sand Stones)
7. Cretaceous.

LOG OF HARROLD WELL.

| | | | |
|---|---|---|---|
| Soil | 2 | 2 | |
| Yellow clay. | 38 | 40 | |
| Blue " | 70 | 110 | |
| Boulder " | 15 | 125 | |
| Blue Shale. | 155 | 280 | |
| Lime Stone | 2 | 282 | |
| Blue Shale. | 168 | 450 | |
| Gray " | 100 | 550 | (streaks of Limestone) |
| Black. " | 50 | 600 | |
| Black Sandy Shale. | 140 | 740 | water rises within 75 ft. top |
| Gray Shale | 160 | 900 | |
| Blue Shale. | 400 | 1300 | small flow at 1000 ft. |
| Shale & Lime streaks. | 133 | 1433 | 3 Small flows. |
| Lignite | 2 | 1435 | |
| Sand Stone | 16 | 1451 | Flow |
| Brown Shale. | 2 | 1453 | |

LOG OF WOLSEY WELL.

| | | | |
|---|---|---|---|
| Black soil. | 1 | 1 | |
| Yellow Clay | 19 | 20 | |
| Blue " | 40 | 60 | |
| Gray Sandy Shale. | 154 | 214 | |
| Dark " " | 276 | 490 | |
| Sand rock. | 10 | 500 | (WATER FLOW) |
| Light Sandy Shale. | 300 | 800 | |
| Conglomerate | 8 | 808 | |
| Sand rock. | 30 | 838 | FLOW |
| Lime " | 20 | 858 | |
| Sand " | 20 | 878 | FLOW |
| Soap Stone | 15 | 893 | |
| Sand rock. | 10 | 903 | FLOW |
| Lime rock? | 27 | 930 | |
| Stopped | | | |

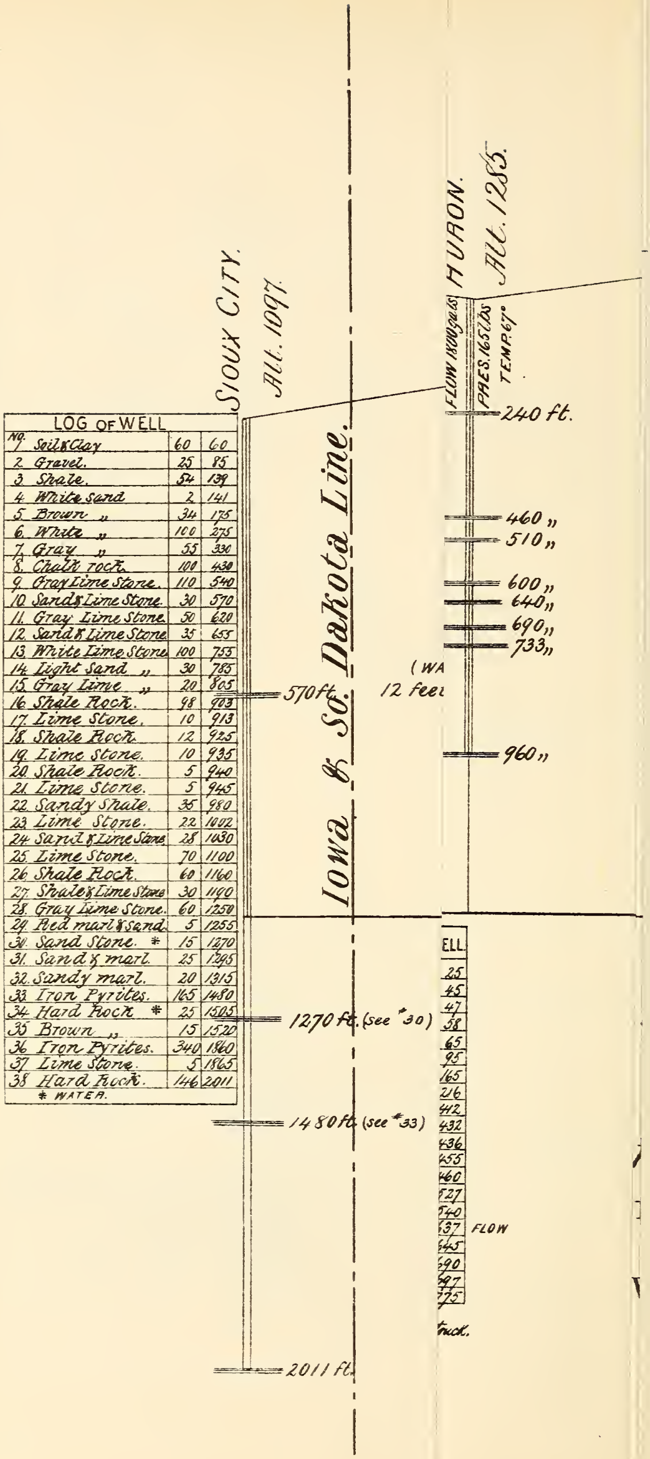
LOG OF RISDON WELL AT HURON.

| | | | |
|---|---|---|---|
| Clay & Shale | 240 | 240 | FLOW |
| Pyrites | 5 | 245 | |
| Shale. | 215 | 460 | |
| Sand Stone. | 50 | 510 | FLOW |
| Lime shell | 2 | 512 | " |
| Shale. | 88 | 600 | |
| Shelly sand | 5 | 605 | FLOW |
| Shale. | 35 | 640 | |
| Shelly Lime | 1 | 641 | FLOW |
| Shale | 49 | 690 | |
| Shelly Lime | 1 | 691 | FLOW |
| Shale. | 9 | 700 | |
| White Shale. | 3 | 703 | |
| Sand Stone. | 30 | 733 | FLOW. |
| Soap Stone & Slate. | 117 | 850 | |
| Flint. | 20 | 870 | |
| Sand & Slate | 20 | 890 | |
| Very hard rock | 12 | 902. | |
| Soft Sand " | 33 | 935 | |
| Soft " " | 25 | 960 | FLOW. Strong. |

LOG OF TRACY WELL.

| | | | |
|---|---|---|---|
| Soil | 1 | 1 | |
| Yellow clay | 19 | 20 | |
| Blue " | 100 | 120 | |
| Sand & Gravel. | 5 | 125 | |
| Blue clay. | 20 | 145 | |
| Sand & Gravel. | 20 | 165 | WATER |
| Gray Shale. | 12 | 177 | |
| Sandy " | 20 | 197 | |
| Gray " | 213 | 410 | |
| Sandy " | 60 | 470 | |
| Brown " | 43 | 513 | |
| Sand & Lime rock | 32 | 545 | WATER |
| Sand " " | 5 | 550 | |
| Sandy Shale. | 30 | 580 | |
| Quartz rock | 7 | 587 | |
| Brown Shale | 24 | 611 | |
| Quartz rock | 8 | 619 | |
| Sand " | 8 | 627 | WATER? |
| Quartz " | 10 | 637 | |
| White marl. | 10 | 647 | |
| Red & white marl | 15 | 662 | |
| Light col'd quartz rock. | 27 | 689 | |
| Red quartz. | 5 | 694 | |
| Granite | 33 | 727 | |

Actual depth 724 ft.
Water rises to 40 ft of surface.
& cannot be lowered by pumping.



| LOG OF WELL | | |
|---|---|---|
| NO. 1. Soil & Clay | 60 | 60 |
| 2. Gravel. | 25 | 85 |
| 3. Shale. | 54 | 139 |
| 4. White sand | 2 | 141 |
| 5. Brown " | 34 | 175 |
| 6. White " | 100 | 275 |
| 7. Gray " | 55 | 330 |
| 8. Chalk rock. | 100 | 430 |
| 9. Gray Lime Stone. | 110 | 540 |
| 10. Sand & Lime Stone. | 30 | 570 |
| 11. Gray Lime Stone. | 50 | 620 |
| 12. Sand & Lime Stone. | 35 | 655 |
| 13. White Lime Stone. | 100 | 755 |
| 14. Light Sand " | 30 | 785 |
| 15. Gray Lime " | 20 | 805 |
| 16. Shale Rock. | 98 | 903 |
| 17. Lime Stone. | 10 | 913 |
| 18. Shale Rock. | 12 | 925 |
| 19. Lime Stone. | 10 | 935 |
| 20. Shale Rock. | 5 | 940 |
| 21. Lime Stone. | 5 | 945 |
| 22. Sandy Shale. | 35 | 980 |
| 23. Lime Stone. | 22 | 1002 |
| 24. Sand & Lime Stone. | 28 | 1030 |
| 25. Lime Stone. | 70 | 1100 |
| 26. Shale Rock. | 60 | 1160 |
| 27. Shale & Lime Stone | 30 | 1190 |
| 28. Gray Lime Stone. | 60 | 1250 |
| 29. Red marl & sand. | 5 | 1255 |
| 30. Sand Stone. * | 15 | 1270 |
| 31. Sand & marl. | 25 | 1295 |
| 32. Sandy marl. | 20 | 1315 |
| 33. Iron Pyrites. | 165 | 1480 |
| 34. Hard Rock * | 25 | 1505 |
| 35. Brown " | 15 | 1520 |
| 36. Iron Pyrites. | 340 | 1860 |
| 37. Lime Stone. | 5 | 1865 |
| 38. Hard Rock. | 146 | 2011 |
| * WATER. | | |

# THE DAKOTA ARTESIAN BASIN.

The extent and capacity of what has become known as the Dakota Artesian Basin widens and deepens the more it is examined.

It is an old and imperishable aphorism, that there is an underlying cause for every effect. It is also admitted on all hands that, while effects may be local in their development, the producing causes may be regional in their extent. In seeking for the breadth and depth of the Dakota Artesian Basin, and for the causes that produce our wonderful artesian wells, distance must be ignored, and local conditions must not always be considered determinal. Between the Great Lakes and the Rocky Mountains geologists inform us there are two vast low synclinals. The axis of one is the Mississippi River, and the axis of the other is the Missouri River. Or, in other words, the Upper Mississippi River system forms one basin and the Upper Missouri River forms the other basin. Each has its system of surface and phreatic or tellurial drainage. There is doubtless another vast artesian basin further north formed by the McKenzie River system, as yet unexplored and undeveloped. There are a number of artesian wells in the Mississippi River system, but no systematic examination has been made with a view to determine the artesian possibilities. The Missouri River system is the one that engrosses our attention, and is the subject of governmental investigation.

By a survey of this vast low synclinal we find its outlines to be as follows:

Commencing on the west we find that the Cheyenne River drains the entire Black Hills, showing that they dip to the north and east. Passing westward to Wyoming we find that the drainage of about half of that State flows to the north into this basin. The eastern slope of the Rocky Mountains in Montana also pours its vast supply of water into this basin. The swell of land near the southern boundary of the British Possessions, that forms the "divide" between the Missouri and the Saskatchawan, cuts off escape for the water in that direction. That the valley of the Red River of the North forms a separate and distinct artesian basin will not be discussed in this report.

The uplift of Laurentian gneiss along the western side of Minnesota, which makes the "divide" between the Mississippi and the Missouri, presents an impassable barrier in that direction. Thus pent up, the water is forced to escape southward.

There is another topographical feature that has an important bearing on this question. By comparing altitudes we find that Wyoming is about 3,000 feet higher than Montana. Also, that the Rocky Mountains where the Union Pacific Railroad crosses is about 3,000 feet higher than where the Northern Pacific crosses, showing a general dip of the body of the mountain to the northeast, which is a hint that the phreatic drainage of the mountains is in that direction, certainly not in the opposite direction.

The numerous hot springs and geysers along the western border of this basin are visible proofs of two important facts: (1) That there is a

U. S. Department of Agriculture,

# PROFILE OF A LINE
FROM
# *Deloraine, Man. to Sioux City, Ia.*
Showing ELEVATIONS, DEPTH OF WELLS
AND
WATER BEARING STRATA

Prepared by FRED. F. B. COFFIN, Civil Engineer

**1891.**

## No. 2.

Scale
Horizontal, 1 Inch = 20 Miles.
Vertical, ½ In. = 200 Ft.

LOG OF WELL

| | | |
|---|---|---|
| NO. 1. Soil & Clay | 60 | 60 |
| 2. Gravel. | 25 | 85 |
| 3. Shale. | 54 | 139 |
| 4. White sand | 2 | 141 |
| 5. Brown " | 34 | 175 |
| 6. White " | 100 | 275 |
| 7. Gray " | 55 | 330 |
| 8. Chalk rock. | 100 | 430 |
| 9. Gray Lime Stone. | 110 | 540 |
| 10. Sand & Lime Stone. | 30 | 570 |
| 11. Gray Lime Stone. | 50 | 620 |
| 12. Sand & Lime Stone. | 35 | 655 |
| 13. White Lime Stone | 100 | 755 |
| 14. Light Sand " | 30 | 785 |
| 15. Gray Lime " | 20 | 805 |
| 16. Shale Rock. | 98 | 903 |
| 17. Lime Stone. | 10 | 913 |
| 18. Shale Rock | 12 | 925 |
| 19. Lime Stone. | 10 | 935 |
| 20. Shale Rock. | 5 | 940 |
| 21. Lime Stone. | 5 | 945 |
| 22. Sandy Shale. | 35 | 980 |
| 23. Lime Stone. | 22 | 1002 |
| 24. Sand & Lime Stone. | 28 | 1030 |
| 25. Lime Stone. | 70 | 1100 |
| 26. Shale Rock. | 60 | 1160 |
| 27. Shale & Lime Stone | 30 | 1190 |
| 28. Gray Lime Stone. | 60 | 1250 |
| 29. Red marl & Sand. | 5 | 1255 |
| 30. Sand Stone. * | 15 | 1270 |
| 31. Sand & marl. | 25 | 1295 |
| 32. Sandy marl. | 20 | 1315 |
| 33. Iron Pyrites. | 165 | 1480 |
| 34. Hard Rock * | 25 | 1505 |
| 35. Brown " | 15 | 1520 |
| 36. Iron Pyrites. | 340 | 1860 |
| 37. Lime Stone. | 5 | 1865 |
| 38. Hard Rock. | 146 | 2011 |
| * WATER. | | |

LOG OF CITY WELL YANKTON.

| | | |
|---|---|---|
| Soil, sand & gravel. | 38 | 38 |
| Chalk rock. | 62 | 100 |
| Shale | 26 | 126 |
| Hard rock | 4 | 130 |
| Sand | 34 | 164 |
| Shale | 65 | 229 |
| Sand | 35 | 264 |
| Shale | 135 | 399 |
| Sand & clay | 100 | 499 |
| Water sand | 106 | 605 |

This is the City well on the bluffs.
The above profile is the Mill well on the flat, with similar strata and flows as represented.
The Cement works well about same strata with flows at 375, 390, 405, 435 and 450 to 500 ft.
No Log could be got of these 2 wells.

LOG OF WOONSOCKET WELL.

| | | | | |
|---|---|---|---|---|
| 1 | Soil & clay. | 25 | 25 | |
| 2 | Blue clay. | 20 | 45 | |
| 3 | Sand | 2 | 47 | |
| 4 | Blue clay. | 11 | 58 | |
| 5 | Hard pan. | 7 | 65 | |
| 6 | Sand. | 30 | 95 | |
| 7 | Hard pan & gravel | 70 | 165 | |
| 8 | Shale & pyrites | 51 | 216 | |
| 9 | Soap stone | 196 | 412 | |
| 10 | Hard sand rock. | 20 | 432 | |
| 11 | Hard Brown " | 4 | 436 | |
| 12 | Soap stone | 19 | 455 | |
| 13 | Soft shale. | 5 | 460 | |
| 14 | Soap stone & Pyrites | 67 | 527 | |
| 15 | " " " " | 13 | 540 | |
| 16 | Sandy Shale & " | 97 | 637 | FLOW |
| 17 | Hard rock. | 8 | 645 | |
| 18 | Shale. | 45 | 690 | |
| 19 | Sandy Shale. | 7 | 697 | |
| 20 | Sand rock. | 78 | 775 | |

Here a good flow was struck.

LOG OF THE J. P. DAY WELL.

| | | | | |
|---|---|---|---|---|
| 1 | Soil | 1 | 1 | |
| 2. | Yellow Clay | 15 | 16 | |
| 3 | Blue " | 20 | 36 | |
| 4 | Sand & Gravel | 36 | 72 | |
| 5 | Soap stone | 350 | 422. | (Gray Shale)? |
| 6 | Conglomerate | 3 | 425 | |
| 7. | Soap stone | 275 | 700 | (flow)? |
| 8 | Pyrites of Iron. | 2 | 702 | |
| 9 | Soap Stone | 100 | 802 | ? |
| 10 | Bastard Limes | 20 | 822. | |
| 11. | Soap stone | 60 | 882 | ? |
| 12. | Pyrites of Iron | 2 | 884 | |
| 13 | Soap stone. | 26 | 910 | |
| 14. | Conglomerate | 7 | 917 | |
| 15. | Sand stone | 78 | 995 | |

In this was a big flow.
The drillers think there was a flow at 400 feet the same as at the Baker well

deep flow of water in this region, and (2) that it is escaping to the east by every possible means.

The surface drainage of this basin is visible, and can be estimated with reasonable certainty. The phreatic drainage being invisible requires the most thorough and exhaustive examination in order to make even an approximate estimate.

To form any adequate idea of the volume of the phreatic waters requires a thorough examination of and acquaintance with the underlying formations. Their capacity of imbibition and transmission of water must be thoroughly understood. Their uniformity of structure must be considered. A sandstone stratum that is close and compact across a given section of country is an effectual barrier to the transmission of water, however open and porous it may be on either side.

Water thus obstructed remains pent up unless it finds a passage over, under, or around. Where the porosity of the rock is continuous, it must have a firm impervious stratum above and below in order to form artesian wells, together with a suitable dip.

The thickness and porosity of the water-bearing stratum, or the combined thickness of the different strata, is an important factor in determining the volume of water that can be obtained.

The examination of this artesian basin has of necessity been a cursory one. But little can be learned from surface indications alone. The wells that have been sunk have been by private enterprise for the purpose of procuring water for various uses, without any purpose of investigation or development. In many cases no record was kept of the formations passed through. Many of those that were kept were not of that accurate character that is necessary to determine the precise nature and order of the formations. Many times the driller did not know what he was going through. When the "log" of the well was made up it was largely made from guesswork and by a man who had no knowledge whatever of geological formations. The "log" of some of the wells has been quite carefully kept, and from these about all the information we have has been derived.

The hasty and general examination that I have made during the last two years convinces me that the artesian basin of South Dakota is much more extensive than was at first considered, and that water can be had much deeper than is generally suspected.

To illustrate my views on this subject, I have prepared two profiles: No. 1, on a line running from Tracy, Minn., to the summit of the Black Hills, in South Dakota. No. 2, on a line running from Sioux City, Iowa, to Deloraine, Manitoba.

At Tracy, Minn., they claimed to have struck granite at 724 feet. It is probably Laurentian gneiss, if the formation is granitic, as that formation comes comparatively near the surface in a large part of Minnesota.

Tracy is on the eastward slope and belongs to the Mississippi basin. The real summit, or "divide," is at Lake Benton. The railroad station, where the elevation is given, is in a depression on the lake shore. The real elevation of the locality must be at least 1,800 feet. Then the slope commences westward.

Just what the dip of the granitic formation is is not known. If it is the boundary of an upheaval it is liable to be quite abrupt. Certain it is that there is no reliable evidence that it has ever been struck between Tracy and the Black Hills.

The general descent continues until we reach the Jim River, then there is a gradual ascent until we reach the foot of the Black Hills.

There is a depression near Brookings, forming the valley of the Big

Sioux River; another one at Pierre, forming the valley of the Missouri River.

The intervening swells of land at Arlington and Highmore in no way affect the underlying formations. The shale under the drift is in position. These ridges or ranges of coteaus were simply left when the valleys of the Big Sioux, the Jim, and the Missouri were eroded by the denudation of the receding waters.

During the drift period these ridges or coteaus made convenient lodgment for moraines. The drift on these ridges is about one-third deeper than in the valleys.

From Pierre east across the State the drift on an average in the valleys is about 100 feet thick. On the coteaus it is from 130 to 150 feet thick. Between Pierre and the Black Hills there is no drift.

By examining the wells on profile No. 1 it will be seen that at Harrold water-bearing sandstone was found at 1,061 feet above sea level; at Huron, 1,045 feet; and at Iroquois, at 1,001 feet, showing a remarkable uniformity of depths. Again, we find water-bearing sandstone at Harrold at 801 feet above sea level; at Wolsey, at 848 feet; at Huron, at 825 feet; at Iroquois, at 801; and at Tracy, Minn., at 858. Again, we find it at 398 feet at Harrold; at 339 feet at Highmore; at 390 feet at Miller; at 396 at Wolsey, and at 380 feet at Huron.

When we take into consideration the inaccuracies that are liable to occur in the measurement of wells this uniformity is remarkable, and certainly establishes the fact that the formations are in place and are level in this locality.

Leaving Pierre and going westward the ascent is gradual. There being no drift to modify the surface it is clear that the shale formations have a general dip to the east. So much for the formations near the surface. What is beneath? We find the geological formations of the Black Hills to be as follows: (See sketch, profile No. 1.) First, granite. Second, Archean schists and slates. Third, Cambrian, Potsdam. Fourth, Carboniferous limestones. Fifth, Jura Triassic, Red Beds. Sixth, Jura Triassic, sandstones. Seventh, Cretaceous. Just how far those formations extend under the cretaceous is not known, and never will be known till deep borings are made. But it is reasonable to suppose that it passes under till it meets the granitic formations of Minnesota.

At Mankato, Minn., they drilled through 522 feet of Potsdam sandstone and found water. At 600 feet they found granite or gneiss. If the lower Potsdam at Mankato is porous enough to furnish water for an artesian well, that sandstone must extend to some mountainous region to receive its supply.

South Dakota lies between Mankato, Minn., and the Rocky Mountains. It is a reasonable inference that the Potsdam passes under South Dakota to the Rockies for its supply of water. With granite beneath and the Carboniferous limestone above it, it is securely guarded. If this hypothesis is true we can certainly get water from it by going down to it.

In the Upper Jura Triassic we have a porous sandstone. There is no proof that it does not pass under us and some proof that it does. It is my opinion that the water at Devils Lake, Jamestown, and the deep flows at Sioux City come from this formation. (See profile No. 2.)

Prof. Culver says the Dakota sandstones crop out at Sioux City. That being the case, we have an additional proof that we have water-bearing formations under us much deeper than any well has ever been sunk in South Dakota. The water-bearing formations at Sioux City certainly pass under South Dakota sandstones in order to reach the source of water supply.

Without going further into details, it seems to me that the preponderance of evidence goes to show that South Dakota lies in a vast deep synclinal composed of numerous water-bearing strata, whose eastern limit is Lake Benton, Minnesota, and the Black Hills on the west, on the line of profile No. 1; that the axis of this basin or valley is near the location of the Jim River, and it may be thousands of feet to the Archean rock at this line.

Take the wells in profile No. 2 and we find that a water-bearing stratum was found at Mellette at 892 feet above sea level, at 825 feet at Huron, at 848 feet at Wolsey (profile No. 1).

At Plankinton a flow was struck at about this level, but as the well is in litigation no particulars were to be had. At Mitchell it was struck at 787 feet; at Armour, 789 feet; and at Yankton, 836 feet.

Again we find a water-bearing stratum at Ellendale at 360 feet above sea level, at 365 feet at Frederick, at 397 feet at Aberdeen, at 384 feet at Mellette, at 336 feet at Redfield, at 389 feet at Hitchcock, and at 325 feet at Huron.

Then we find water at Jamestown at 151 feet below sea level, and at 86 feet below at Devils Lake, while at Deloraine, Manitoba, water has not yet been reached at 152 feet below.

This certainly discloses the fact that at about 830 feet above sea level there is a stratum of water-bearing sandstone that is practically level. Then at about 350 feet above sea level there is another. That from 100 to 150 feet below sea level (I think lower) another general stratum will be found.

If, as some suppose, the water-bearing sandstone has an irregular dip northward, that the well at Jamestown receives water from the same stratum that the wells at Aberdeen, Redfield, Huron, etc., do, we would expect to find it deeper at Devils Lake than at Jamestown, but the reverse is true. Thus the stratum would pitch down from Ellendale to Jamestown, then rise to Devils Lake, then down again to Deloraine. Thus it would be traveling up and down through the earth while the other formations were in position, a very singular thing to do.

We see from the record of the wells that there is some irregularity in the water-bearing formations. That is, in one locality a water-bearing formation will be thick enough and porous enough to furnish a good supply of water. Perhaps in the next well that stratum will be pinched out, or so dense as to furnish no perceptible quantity of water. To this fact I think we may look for the reason why no water was found at Jamestown and Devils Lake on the same level with Ellendale, Aberdeen, etc.

It is my opinion that the water-bearing sandstones that we find in South Dakota in the first 1,000 or 1,200 feet is wanting in North Dakota.

There has been trouble in getting artesian wells in the southeastern portion of the State, owing to what is known as Sioux Falls quartzite. This has been a fruitful cause of trouble in two ways: First, this rock has been a real obstacle in sinking wells; and second, it has been a convenient pretext for some drillers to quit work when they got into trouble.

It has been generally believed that this rock was a true Archean rock—that it rested upon the underlying granite, and hence that when this rock was found it was useless to attempt to go farther, as no water could be found.

From most of these propositions I dissent. That it is Archean in its formation I admit. But in the time of its formation it is quite recent. That it is not a primordial formation, and does not rest upon the granite necessarily. That heat was not an agent in its metamorphism, but that water was. That its presence is not conclusive evidence that water can not be found under it, but that it is quite probable that water can be found under it.

Now, what led me to these conclusions? As far as I know, this rock is in position everywhere. That it is a part of the Cretaceous formation. There is no evidence of an upheaval. I know of no other source of heat sufficient to cause the metamorphism but the internal heat of the earth. I know of no way for it to escape but through a fissure. If there has been no upheaval, there has been no fissure. That the metamorphism was caused by the action of water there is abundant reason to believe. That it is recent is evidenced by the fact that it conforms to the recent formations about it. That it is shelving, that these shelves have been passed through, and water found under them.

Now for the details. This rock is a pure quartzite. The glass reveals the grains of sand with their outlines clearly defined. It is plain that the sand has been cemented by silica into a compact crystalline mass with enough iron to give it its different shades of color. It is the disposition of everything in this country to silicise, and it has probably been more so in the past.

What is known as Grindstone Buttes, about two-thirds of the way from Pierre to the Black Hills, are capped by a conglomerate. Upon examination it is evident that the sand and gravel have been cemented by silica deposited by the water when the country was submerged. Bijou Hills in Brule County are capped by a similar formation. I should not be surprised if an examination would disclose a line of hills similarly capped, lying in the general direction of these Buttes, and that a connection could be traced between them and the Sioux Falls formation.

It is a noticeable fact that the sandstone in this country is of all degrees of hardness. Sometimes it appears to be a bed of loose sand. From this, by easy gradations, it becomes a dry, firm, hard sand rock, and, as I believe, to the hardest quartzite.

At about 1 mile east of Alexandria, in Hanson County, in a creek bottom, the quartzite crops out. This is a firm, well formed quartzite. The streets of Alexandria are about 35 or 40 feet above this outcropping of quartzite. In sinking a well in town, at about the level of the quartzite, they found sandstone, not water-bearing, but easily drilled. They went down 200 feet without finding quartzite. They got water that rose to about the level of the quartzite.

At Bridgewater, McCook County, at a depth of 185 feet, the drill struck quartzite. I have a specimen of this rock, and know that it is quartzite. This stratum was 3½ feet thick. At 231 feet they found an abundant flow of water.

A short distance west of Bridgewater, in a creek bottom, the quartzite crops out. The water has cut a channel through it, and shale is found under it. At about the same level quartz sand was found in the Bridgewater well. One half mile west of this outcropping a well was bored. At about the level of the quartzite at the creek sand rock was found. Drilling through this at about 100 feet, water was found in sandstone that rose to about 25 feet of the surface.

On the farm of Henry Ramsdell, in the northeast part of McCook County, at about 100 feet, hard red quartz rock was struck. A little over a mile west of this, at 115 feet, apparently the same formation was struck, but here it was yellow sandstone, 30 feet thick, with an abundance of water.

At Vilas, Miner County, at a depth of 480 feet, the driller claimed he struck quartzite, and quit. At Madison, Lake County, the same driller with the same machine, at about the same level, claimed that he had struck the same formation, and insisted that it was useless to go farther. The authorities insisted on continuing the work, and it was continued, the hard rock was drilled through, and shale was found beneath it. When I last visited the well they were down 1,000 feet and just entering sandstone.

The altitude of Madison is 1,639 feet; that of Vilas is 1,480; making Madison 179 feet higher. Add 460 feet, the depth of the Vilas well, to 179, the difference of altitude, and we have 639 feet, the depth at which quartzite might be expected at Madison, and here we find at a depth of 575 feet a hard sandstone 80 feet thick, taking us to 655 feet. Under this was a black sticky shale 75 feet thick; then 40 feet of coarse dark sandstone, then 30 feet of shale, then sandstone that has as yet not been gone through. It seems to me that these facts indicate very strongly that the presence of quartzite is not necessarily an insuperable barrier to an artesian well.

The question can not be settled by surface examination alone. It is folly to attempt it. The only sure and practical way to settle this question is the careful and judicious sinking of test wells.

There is another problem that does not yield to a ready solution. By reference to profile No. 2 it will be seen that the wells near Plankinton do not go as deep as those either north or south, particularly north. The question naturally arises, why is this? It is claimed that Plankinton is on a ridge or spur of the quartzite formation that projects westward towards the Missouri River. The drillers claimed to have struck the quartzite at Plankinton, White Lake, and Kimball, the two wells west of Plankinton, and said there was no hope of getting water below it. If that is true, there are certain conditions that I would like to have explained.

At Plankinton the flow is 224 gallons per minute, and the pressure is 47 pounds to the square inch, closed pressure. At White Lake and Kimball west it is still less. At Mitchell, in the Jim Valley, a somewhat similar condition exists. East of Mitchell there are no successful deep wells. So it seems that there is a strip running east and west where it is difficult to get water. This condition seems to terminate at Chamberlain, as they have a good well there.

Now if the quartzite has been reached in this strip and there is no water under it, and the supply of water over it is scant, how can we account for the wonderfully free-flowing wells south of it?

As soon as we cross the ridge we have a very free-flowing well at Armour, furnishing 1,443 gallons per minute, more than twice the quantity of water that all the wells on the ridge combined furnish. The city of Yankton has three large wells furnishing together over 5,000 gallons per minute. At Springfield they have an 8-inch well that throws 3,293 gallons per minute.

It is hardly possible to suppose that the water comes from the west under Nebraska, as the wells at Santee Agency and at Fort Pandall are not classed as strong wells. Neither have there been any strong wells discovered along the eastern borders of Nebraska.

There seem to be but two theories: One that the water goes around, and the other that it passes under. It is hard to account for the Armour well on the theory that it goes around. If the water goes around the Fort Randall well should be a better one. The Chamberlain well is a good one, but it does not indicate the presence of the quantity of water that would be there in the case of the escaping water passing that way.

Now let us try the theory that it goes under the hard sandstone on which the drillers stopped. It will be noticed that the pressure of the wells north of this close strip is much greater than of the wells south of it, indicating certainly that in the latter case resistance is stronger still.

The nearest wells north are at Woonsocket. The city well, before it caved in, had a pressure of 155 pounds to the square inch and a flow of 2,700 gallons to the minute when measured by the Government agent in June, 1890. The mill well has a flow of 1,500 gallons per minute and a pressure of 125 pounds.

When we go south of this strip the flow of the wells materially increases, while the pressure rapidly decreases, the pressure north of good wells being about 150 pounds, and south about 50 pounds.

The resistance offered by this close strip will account for the high pressure and good flow north. The loss of pressure south indicates that water has escaped from the resistance. The full flow south is caused by the great thickness of the water-bearing sandstone and its open, free nature. It is my opinion that if a deep well was sunk in this close strip a good flow of water would be found that would solve the whole mystery.

They have had the same trouble at Scotland as at Mitchell, and I think the same remedy will apply—go deeper. If it is demonstrated that wells can be had in this quartzite district, it will doubtless be more difficult to get them, but I think the wells will be more durable, as the walls will be firmer, and will stand better.

If Congress could be induced to make an appropriation large enough and liberal enough in its provisions to allow the sinking of a sufficient number of test or experimental wells we could then demonstrate the nature and extent of the quartzite district, the depth of the basin in the Jim Valley, and the possibility of getting good artesian wells on what is known as the reservation or the unsettled portion of the State between the Missouri River and the Black Hills.

All of which is respectfully submitted.

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